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THE USE OF THICKNESS CONTOURS IN THE VALUATION OF LENTICULAR COAL BEDS.[1]

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INTRODUCTION.

The coal beds of the Tertiary and Cretaceous formations of the western states are generally lenticular in character, and many of them occupy small basins whose extent may be determined with considerable accuracy. Other beds may be traced over large areas, but outcrop measurements show that they vary greatly in thickness. In attempting to define accurately the workable limits of such coal beds or to estimate the tonnage of coal which they contain, thickness contours have proven of great value. Thickness contours or isopachous lines, as the terms imply, are imaginary lines connecting points of equal thickness; they furnish a convenient method of summarizing all the data at hand concerning the thickness of a coal bed so that its estimated thickness at any point may be at once ascertained. The process of drawing these lines, as in the case of structure contours, demands a considerable amount of field data, sometimes more than it is desirable to collect; but if conditions are favorable their use not only furnishes the most reliable basis for the valuation and economic treatment of the coal bed, but brings out many facts of scientific interest as well. The following paper is a discussion of this device for epitomizing thickness data, with its advantages and limitations, and is accompanied by several examples of its use.

[1] Published by permission of the Director U. S. Geol. Survey.

During the past six years the U. S. Geological Survey has been actively engaged in the classification and valuation of public coal land. When this work was first undertaken an attempt was made to classify land underlain by lenticular coal beds on the assumption that such deposits are roughly circular and that the center of the circular lens is on the outcrop.

This assumption must still be made where data are insufficient but experience has shown that in detail it is commonly incorrect. Since the requirements of this work as to accuracy are very exacting, thickness contours were later employed as the most reliable basis for valuation estimates. The results were so satisfactory that this method is now used wherever field conditions permit.

It is obvious that the value of thickness contours in any case depends on two factors: the accuracy with which they may be determined, and the amount and character of the variation which they are intended to bring out. Thus, it is impossible to draw contours with any degree of confidence when the data at hand consist only of a few sections measured along a comparatively straight outcrop. The method cannot therefore be satisfactorily applied to steeply dipping beds unless a considerable amount of drilling has been done back of the outcrop. The ideal condition is that in which the coal is practically flat-lying and underlies a dissected ridge, so that the outcrop is a fairly sinuous line. If the numerous sections measured along the outcrop are then further supplemented by drilling at doubtful points the contours may be used as a satisfactory basis for the most refined tonnage and valuation estimates. The accuracy of the contours therefore depends not only upon the amount of data but also upon its proper horizontal distribution. On the other hand, if the coal bed maintains a practically constant thickness over a large area, as in many of the eastern coal fields, thickness contours are obviously of little value regardless of the accuracy with which they may be drawn. Or, to cite the opposite case, if the coal bed is extensively dissected by shale or bone channels or "rolls," it would be practically impossible without mine data to draw contours accurately bringing

out these abrupt variations. The method is of greatest value therefore when applied to flat-lying or slightly dipping coal beds, the thickness of which varies considerably in a more or less regular manner; and these conditions are met most commonly in the Cretaceous and Tertiary coal beds of the west.

METHOD OF DRAWING THICKNESS CONTOURS.

Since many coal beds are split by bone or shale partings, which are not only worthless but actually detrimental, it is first necessary to express the sections of such beds in terms of workable or usable coal, *i. e.*, the split bed must be evaluated before it can fairly be compared with an unbroken one. It is impossible to formulate a method of allowing for partings that applies equally well to all coal beds and under all conditions of mining; but it is the conservative practice of the U. S. Geological Survey to assume that "Any parting or bench of bone or impure coal included in a bed injures the value of the coal of the bed in amount equal to the thickness of the parting."[1] The cost of removing a parting, in other words, is assumed to be about equal to the profit on the same thickness of coal. For example, if the bed consists of two benches of coal, each three feet thick, separated by one foot of shale, this bed is considered the economic equivalent of one consisting of five feet of unbroken coal. Or, if the upper bench of this bed is only one foot or less thick, the value of that bench is held to be nullified by the cost of mining the one-foot parting and the bed is considered for practical purposes to be only as thick as the lower bench. If the bed consists of a number of benches separated by partings the best bench is selected and given full value, and the thickness of the adjoining benches minus that of the intervening partings is then added, omitting of course any bench which is thinner than the contiguous parting. This method is confessedly a general one and may in some fields be unduly conservative in the matter of allowance for partings; it is suggested here merely as the best uniform system, which may be altered as desired to meet local conditions.

[1] Smith, G. O., and others, "The Classification of the Public Lands," U. S. Geological Survey Bull. 537, p. 70, 1913.

It is evident that the method of standardizing sections outlined above is purely economic in its purpose and does not necessarily express the total amount of coal in a bed. Thus, a bed may be 30 feet in total thickness and yet be so badly split by partings as to have an economic value of only two or three feet. For scientific purposes it may sometimes be important to show the total thickness of the bed or to take the partings into account in some other way, points which the economic method is in fact intended to eliminate. This question will be referred to again in connection with the scientific value of thickness contours.

After the measured sections of the bed have been standardized in some way and the calculated thickness plotted on the map the contours themselves may be drawn. It may be borne in mind that this process is entirely similar to that of drawing structure contours, or of constructing a topographic map in the office from level and transit notes. The first step is to locate by grading the exact points through which the various contours must pass and the second to connect these points with the contours. The contour interval may be determined by the amount of data at hand and by the amount and character of thickness variations, but in general a 6-inch interval has been found the most satisfactory.

If contours are to be drawn for every six inches in thickness variation, starting, for example, with 18 inches, as many points as possible at which the coal is 18 inches thick are to be determined. If one section shows 12 inches and the adjoining one 24 inches it may be inferred that the coal is 18 inches at a point halfway between them, and that the 18-inch contour must therefore pass through that point. Where the problem is less simple, as in determining an 18-inch point between 15- and 25-inch sections, a graphic method involving the use of cross-section paper will be found most convenient. After as many 18-inch points as possible have been determined sections may be selected for locating the 24-inch points and so on. In cases of insufficient data it may be necessary at times to determine a contour point by projecting from two measured sections rather than grading between them. That is, if the bed is 36 inches thick at a certain place and 30

inches one mile away, it may be necessary to assume that the 24-inch point is exactly one mile farther. Such an assumption is at best only approximate, and need seldom be resorted to. Inasmuch as the thickness variation is generally not quite uniform even in short distances it is desirable to utilize all the data at hand and to locate as many contour points as possible. Conflicting locations obtained by the use of different sets of sections, may may be adjusted later when the contours themselves are drawn. Thicknesses actually measured should of course be given the greater weight.

In practice it will be found desirable to distinguish on the map between the measured thicknesses and those obtained by grading between them, as for example, by indicating the positions of the former by an arrow and those of the latter by a cross.

When as many points as desirable have been located on the map by grading, the contours themselves may be drawn. No general rule for drawing them can be given, and in many cases it will be found that they may reasonably be drawn in several ways. Each case requires special study, and several types are illustrated below. In general it is best to draw the simplest contour first for it will probably furnish a valuable clue to the general shape of the other lines; but it is always advisable to start tentatively and to experiment with several lines before choosing one for this purpose. If the measurements show at a glance that the contours are comparatively straight lines, the "simplest" may be merely the one concerning which there is the most data; but if they are concentric or closed it will probably be the shortest. Thus, in the first example given below, the 54-inch contour, being the simplest, was the first drawn, and it at once made the general disposition of the adjoining lines apparent. In many cases the location of some particular contour at a certain place may be in doubt until the adjoining lines are drawn. These will then generally suggest the shape of the doubtful line, for thickness contours, like topographic and structural contours, generally exhibit a marked "sympathy" for each other. For example, if the measurements indicate that the 36- and 18-inch con-

tours are abruptly embayed in a certain locality it may be inferred, in the absence of direct information, that the 30- and 24-inch contours are roughly conformable to them. That this rule holds in the case of thickness contours is somewhat remarkable in view of the artificial reduction to which many of the measurements are subjected, but several illustrations of this principle will be found in the examples given below.

When the position of the contours is doubtful they should always be distinguished, as, for example, by a broken line. In the first illustration given below it will be noted that the position of the contours in the southeastern part is entirely inferred. As shown below, there are reasons for drawing the lines in this way; but, unless the doubtful parts are distinguished, it is very easy after the contours are all symmetrically drawn to forget the points of doubt which arose during the actual process of construction and to assume that they are everywhere equally accurate.

EXAMPLES OF THE CONSTRUCTION AND USE OF THICKNESS CONTOURS.

The following examples have been chosen by the writers with certain definite ends in view. During the past six years, in the course of classifying and appraising the public coal lands, the U. S. Geological Survey has examined a large number of Cretaceous and Tertiary coal beds in the western states. Many of these beds are distinctly lenticular, and as they are for the most part undeveloped, information as to the thickness and extent of the bed must be obtained almost entirely from outcrop measurements. Thus, thickness contours, while they find their broadest application in these western fields, are at the same time there put to the severest practical test. In order to show, therefore, what may be done under the ordinary conditions in which all information is derived from a study of the outcrop, two examples have been selected from the large number in the files of the Land Classification Board of the Survey. The first case is one in which the measurements are numerous and rather exceptionally well placed, and in which the contours indicate a symmetrical de-

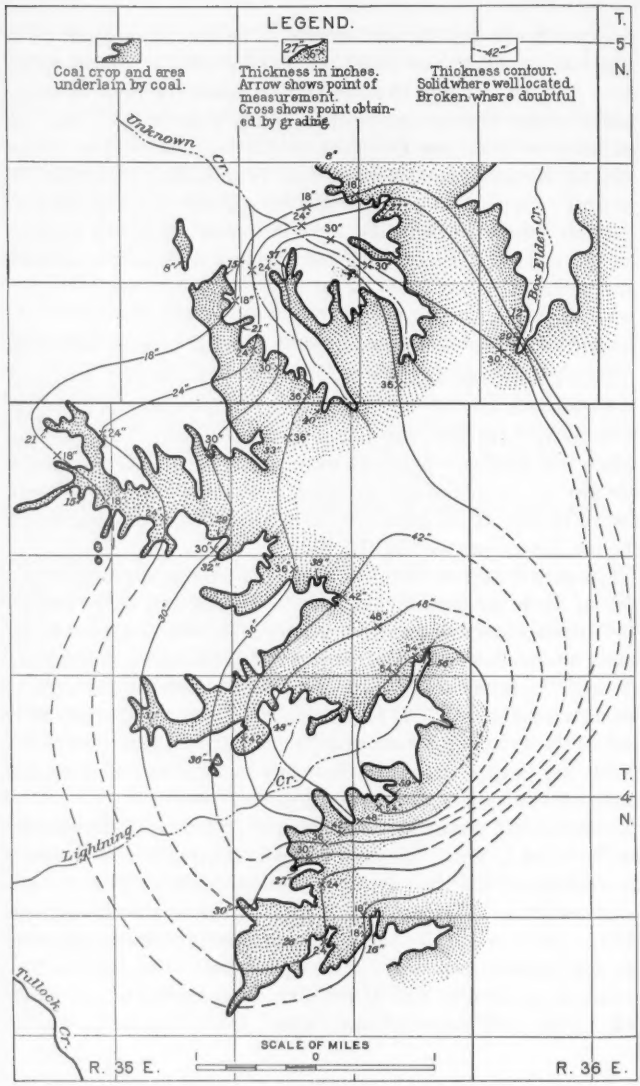
posit of fairly well defined extent. The second is based on a study of the outcrop of a coal bed on both sides of a large valley for a distance of about 18 miles and illustrates the value of thickness contours in summing up data over a considerable area. In addition to these two examples, which are drawn from undeveloped western fields, a third case is presented in which the method is applied to a thoroughly prospected Appalachian coal bed. It is believed that these three examples will suffice to show the use and the value of thickness contours under the conditions most commonly met.

Example 1. Coal Bed near Bighorn, Rosebud County, Montana.

Description of Field.—The area shown on Plate XVI. is located in the eastern side of the angle formed by Yellowstone and Bighorn rivers three miles east of the town of Bighorn. The field of which this area is a part was examined by G. S. Rogers in the summer of 1912, and the thickness contours shown below were drawn by him as the basis for the classification and valuation of the coal land controlled by this bed.

The area shown on Plate XVI. comprises the northwestern portion of the broad high divide between Tullock and Sarpy creeks. The drainage is therefore to the west into Tullock Creek and to the north into Yellowstone River by way of Unknown and Boxelder creeks. To the east lies the main divide, which is 4 miles wide at its narrowest point. The relief within the area is about 700 feet, and, as shown by the intricacy of the coal outcrop, the flanks of the divide are deeply dissected. In many cases a bad land topography obtains, and exposures are in general good.

The coal bed occurs in the upper part of the Lance formation, of Tertiary(?) age. The general dip of the strata is to the south at an angle of less than 1°, though abrupt dips of 5° or 6° are not uncommon. The outcrop of the coal bed as shown on Plate XVI. was meandered by plane-table and stadia methods and each point of measurement was accurately located. The bed was followed along the west side of the divide and around on the north side as far as Unknown Creek, where it is below 18 inches in


LEGEND.
Coal crop and area underlain by coal.
Thickness in inches. Arrow shows point of measurement. Cross shows point obtained by grading.
Thickness contour. Solid where well located. Broken where doubtful
T. 5 N.
Unknown Cr.
Bear Elder Cr.
Lightning Cr.
Tullock Cr.
T. 4 N.
SCALE OF MILES
0
R. 35 E.
R. 36 E.

Thickness contours on coal bed near Bighorn, Rosebud Co., Mont.

thickness. Its outcrop was not followed entirely around the north end of the divide, which extends some 4 miles farther than shown on the map, but the exposure in Boxelder Creek was satisfactorily correlated by reference to an underlying coal bed which was traversed the entire distance around the end of the ridge. To the east the nearest exposure of this horizon is about 3 miles distant from the head of Lightning Creek, and in that locality the coal bed is only a few inches thick.

The detailed measurements of the bed in Lightning Creek and to the south show it to consist in general of one bench unbroken by partings. To the north of that creek, however, it is nearly everywhere divided into two benches by a shale parting ranging in thickness from 1 to 12 inches, and in Unknown Creek it is further broken up by several other 1- or 2-inch partings. In determining the thicknesses shown on Plate XVI. these partings were allowed for according to the system described above. No drilling has been done in this area and all data used were derived from a study of the outcrop.

Construction of the Contours.—On Plate XVI. are shown the outcrop of the coal bed and the locations of the 24 measurements made in the field. Of these 18 show the bed to be thicker than 18 inches and 6 show it to be thinner; and in addition to these measurements the bed or its horizon was examined at several places north and south of the area shown on the map and also on the east side of the main divide, and in these localities was found to contain less than six inches of coal.

Inasmuch as the two sections at the head of Lightning Creek are the only ones that show the bed to be thicker than 54 inches, it is evident that the area in which the coal is known to be thicker than that is small and relatively easy to define. As a first step therefore, three contour points were established by grading between the 56-inch section and the neighboring 38-inch and 48-inch sections; and between the 59-inch section and the 27-inch section to the southwest. It is evident from the relative position of these three contour points (indicated on Plate XVI. by crosses) and also from the smaller thicknesses measured farther down Lightning

Creek that the 54-inch area does not extend very far to the west. Its western boundary is well controlled by the three points, but to the east nothing is known of the bed except that it almost disappears within about four miles, and the eastern boundary of the 54-inch area was therefore temporarily left open. The 48-inch contour is controlled by two graded points and by the 48-inch section actually measured, but the determination of its eastern course is a similar problem. The 42-inch contour is controlled by three points on the west, but its northerly course is in some doubt owing to the 40-inch measurement at the head of Unknown Creek, which the contour should normally approach, and to the inadvisability on the other hand of assuming on so slender a basis that a long narrow tongue of 42-inch coal projects a mile or more north from the main body. In any case, however, it is obvious, since the bed is known to disappear to the east within four miles, that the contours are closed and furthermore that they are roughly concentric.

The 36- and 30-inch contours which are located by sections along the west outcrop conform to this plan. The 24- and 18-inch lines are entirely hypothetical in the southwestern part of the area, but from the general arrangement of the other lines it may safely be assumed that they are conformable to the higher contours. Inasmuch as their courses lie entirely in the area from which the coal has been eroded their exact position is a matter of no economic importance, although it is well, in order to complete the general plan of the contours, to draw them all, however slender the basis. All of the contours are well located in the northwestern and northern parts of the area (see Plate XVI.) and their course in the northeastern part is decisively controlled by the two sections measured on Boxelder Creek.

It now remains to connect the contours around the eastern side of the area. Owing to the lack of data in this district it is rather a question of deciding upon a reasonable basis the approximate eastern limit of workability of the bed than of attempting to draw contour lines. The measurement made four miles to the east is too far away to use in grading, especially as it shows only

five inches of coal; for experience in other parts of this field has shown that a coal bed may decrease in thickness to a few inches and then maintain about that thickness for several miles. It may be taken, therefore, merely as indicating that the bed is 18 inches thick at some intermediate point. A more satisfactory basis for determining the eastern limit is the general trend of the contours in the northern and southern parts of the area. In Unknown and Boxelder creeks the 18-inch and 24-inch contours are well located and at the head of the latter creek they pursue a southeasterly course which, if projected, would carry them a little farther east than they are drawn on Plate XVI. In the southern part of the area the contours are not as well located but the general relation of the outcrop measurement suggests that the contours swing around to the northeast. They are therefore connected with considerable confidence as shown on the map, although all the evidence is indirect.

It is of interest to note a marked case of sympathetic variation between the contours in this area. The two most southerly measurements, which are on a direct east-west line, show 16 and 26 inches, and the 18- and 24-inch contours are therefore diverted here from their normal curve to a due north-south direction. The two measurements to the north, 27 inches and 30 inches, are so located that the 30-inch contour is similarly diverted and is nearly conformable to the lower lines. In the district north of Lightning Creek the 30- and 36- inch contours are also roughly conformable, although their course is controlled by different measurements; and other less striking examples will be found on Plate XVI.

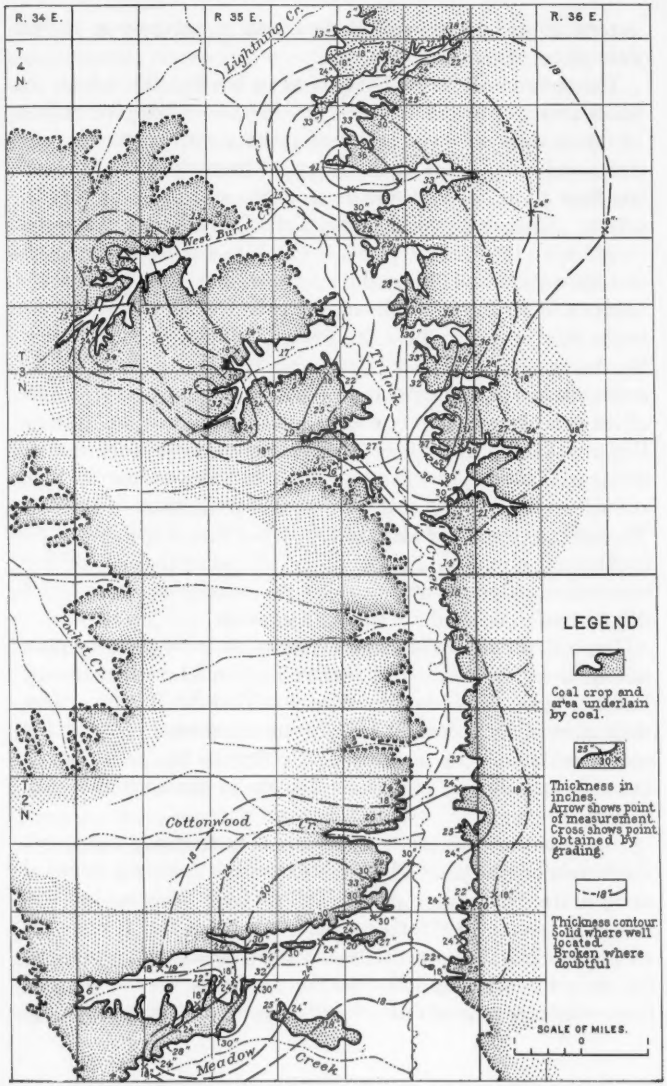
Value of Thickness Contours in This Case.—Notwithstanding the fact that the thickness contours on Plate XVI. are controlled by only 24 outcrop measurements every detail of their construction as briefly explained above rests upon reasonably valid assumptions. The contours bring out strikingly the thickness variation of this coal bed and demonstrate clearly that the bed is thickest at the head of Lightning Creek and that it decreases from that locality in all directions. The coal bed, or rather that portion of it

which is more than 18 inches thick, is probably roughly oval or circular in shape; and this inference was made larely on the evidence of the contours. It would have been impossible to obtain a reliable conception of its shape by attempting to draw merely the limit of the bed or the 18-inch line; it is necessary to use all the measurements available and to take into account the bearing which even the thickest measurements have in determining this line. It is believed that the contours as now drawn are sufficiently reliable and accurate for a reasonably close estimate of the tonnage of this bed.

Example 2. Coal Bed on Tullock Creek, Rosebud County, Montana.

Description of Field.—The area shown on Plate XVII. adjoins on the south that described in example 1, being located on Tullock Creek, about 6 miles southeast of the town of Bighorn. The area was examined by G. S. Rogers and the thickness contours shown were drawn by him and used as the basis for the classification and valuation of the coal land.

Tullock Creek, occupying a steep-sided valley a mile or more broad, flows north across the area shown on Plate XVII. This area includes the crest of the divide between Tullock Creek and Bighorn River on the west and extends almost as far as the top of the eastern divide of Tullock Creek. The drainage is therefore all into the creek, with the exception of minor districts along the western border, which drain to the west into Bighorn River. The difference in altitude between the floor of Tullock Valley and the tops of the divides is about 400 feet. The coal bed here discussed marks the base of the coal-bearing member of the Lance formation, which is about 300 feet thick. The coal-bearing strata form an escarpment which rises steeply from the land underlain by the lower part of the Lance formation, and exposures are therefore generally good. The strata commonly lie at angles less than 2°, though abrupt dips as high as 14° have been observed. As suggested by the shape of the coal outcrop, the area is crossed by a very gentle syncline pitching to the southeast.



Thickness contours on coal bed on Tullock Creek, Rosebud Co., Mont.

Several normal faults with displacements ranging up to 70 feet were observed.

The outcrop of the coal bed or of its horizon throughout the whole area is shown on Plate XVII. Where the bed is more than 18 inches thick its outcrop was meandered with plane table and stadia and every point of measurement precisely located; where less than 18 inches thick the outcrop was sketched with less accuracy. Thus, on the west side of Tullock Creek the bed was traversed from the head of Meadow Creek to a point a little north of Cottonwood, and also in three apparently isolated areas at the heads of West Burnt Creek and the two creeks to the south, but in the intervening districts the bed is less than 18 inches thick. On the east side of Tullock Creek the outcrop was traversed the entire distance from the south line of T. 2 N., to the north border of the area shown. Everywhere on the west side of the Tullock-Bighorn divide the bed is only a few inches thick. The eastern divide of Tullock Creek is about 10 miles wide, and on the eastern side of the ridge no coal was found at the horizon of this bed. The bed may readily be identified by its position at the base of the coal-bearing strata and by a peculiar, thin, sandy parting which it seems invariably to contain, so that the correlations upon which this discussion is based are reasonably certain.

The bed varies considerably in thickness from place to place and in many localities it is broken by several small partings. In determining the thicknesses shown on Plate XVII. the partings were allowed for according to the system described above. The coal is subbituminous in quality. No drilling has been done in this area and all data were derived from an examination of the outcrop.

It may be well further to emphasize a fact already suggested, for therein lies the point which this example is primarily intended to illustrate: On the east side of Tullock Creek the coal bed was traversed continuously for 14 miles in the belief that it was over 18 inches thick for practically the entire distance. Only two measurements showing less than that thickness were made, and those within a quarter mile of each other; and the general im-

pression derived from a field study of the outcrop was that these measurements represented only a local condition and that the bed was thicker than 18 inches throughout a large area to the east, possibly roughly semi-circular in shape and with a diameter of some 14 miles. When all of the data were coordinated in the office, however, and the thickness contours drawn, the significance of these two measurements was clearly brought out, and, as shown on Plate XVII., a radically different conception of the extent of the bed was obtained.

Method of Drawing Contours.—Inasmuch as a rather full explanation of the method of drawing contours is given above under example 1, a detailed description will not be repeated here. As many points as possible were established by grading between measured sections and are shown on Plate XVII., so that the details of the process may be worked out by the reader if desired. Some doubt as to the location of the contours in certain localities must inevitably remain, however, and the broader assumptions made will be considerably below.

The chief point of difference between the lenses shown on Plate XVII. and that on Plate XVI. described above is the method of determining the eastern limits. Owing to the slight easterly dip in this area, the coal outcrop on the east side of Tullock Creek is fairly straight, and, except in the northern part, there is little information as to the thickness of the coal east of the main valley. That there are two lenses rather than one large area, as was thought probable in the field, is shown conclusively by the sections measured along Tullock Creek, and these sections furthermore define the north and south limits of the two lenses. There are three methods by which the eastern boundaries might be located: by drawing a semicircle on the diameter formed by the north and south limits of the lens, by connecting these limits with a more or less flattened arc, or by grading eastward by projection from the measurements at hand. The first two methods are confessedly general and inexact and take little account of the thickness of the bed at the outcrop; the third is based upon all available data and is therefore likely to be the most nearly correct.

Thus, the eastern limit of the southern lens is controlled by two points, the southern determined by projecting from the neighboring 22- and 20-inch sections, and the northern from the 25-inch section and the 33-inch on the west side of Tullock. The latter is of smaller value owing to the distance between the three points involved, and to the improbability of the coal varying absolutely uniformly in thickness throughout this distance. The eastern limit of the northern lens is controlled by three points located in a similar manner. The northermost is determined by projecting from two sections on East Burnt Creek nearly three miles away, and may be regarded merely as an indication of the approximate eastern limit of the workable coal.

It is evident that the western extent of the southern lens in the neighborhood of Cottonwood Creek is entirely hypothetical. On the west side of the divide the horizon of the bed is exposed about a mile west of the area shown, and although 30 inches of coal at approximately the same horizon appears at one point, the bed is less than 18 inches thick within a short distance on either side. Even assuming that this bed is identical with the one which outcrops on Tullock Creek, it is believed that its 30-inch thickness is a very local condition and that this lens is independent of the main one. The 18-inch line of the main lense is therefore drawn entirely from the data obtained within the area shown, its general course being suggested by the shorter and better located 30-inch contour.

The construction of the western side of the northern lens is also somewhat uncertain, especially in regard to the relation which the coal exposed in the western part of the township bears to the main body. Owing to the topographic accident by which the coal is exposed only at the heads of three creeks, it may seem at first that these should be considered three isolated areas, but a further study leads to the belief that these areas are underlain by one lens, as shown on the map, and that in all probability this lens is connected with the main body east of Tullock Creek. All of the measurements, even those showing less than 18 inches,

support this hypothesis, although the exact shape of this small lens, especially on the southwest and the north sides, cannot be determined. On the west escarpment of the divide, which lies less than half a mile west of the area, no trace of the bed is found, and it is probable, therefore, that the lens is not much larger than shown on the map. The general shape of the main northern lens is fairly well determined, except on the east side as discussed above. Although the outcrop measurements for nearly two miles in the northern part of the township show less than 30 inches, it is believed, from the disposition of the other sections to the north and south, that the 30-inch contour encloses one large area, as shown, rather than two isolated areas. The course of the 18- and 24-inch contours is fairly well located by the measurements on the west side of Tullock, although since the coal is eroded in the valley their location is of small economic importance.

Value of the Contours in This Case.—Despite the uncertainty which attaches to the position of the contours in a few localities, there is little doubt that the lenses shown represent approximately the true condition. The use of the contours brings out strikingly the strong improbability of the correctness of the impression gained in the field, namely, that the coal underlies a large area to the east. It is true that the eastern limits of both lenses are more or less uncertain, and it is not impossible that the coal extends much farther east than shown on the map; at the same time, however, the outcrop measurements discourage this view and tend to support the general outline of the lenses as shown. The enormous difference between tonnage estimates made on these two hypotheses is obvious, and the careful consideration of all the evidence is therefore of paramount importance. This example well illustrates the value of the contours in summing up the evidence, and also the fact that while not necessarily correct in detail the contours furnish the most reliable basis for generalizations as to the extent of the bed.

Example 3. Upper Banner Coal Bed in Russell Fork Coal Field, Dickinson County, Virginia.

Description of Field.—The area shown on Plate XVIII. is a part of the Russell Fork coal field, described by R. W. Stone,[1] which is located in Virginia near the Virginia-Kentucky line. The writers are indebted to Henry Hinds of the Geological Survey for the detailed coal data shown on the map (Plate XVIII.).

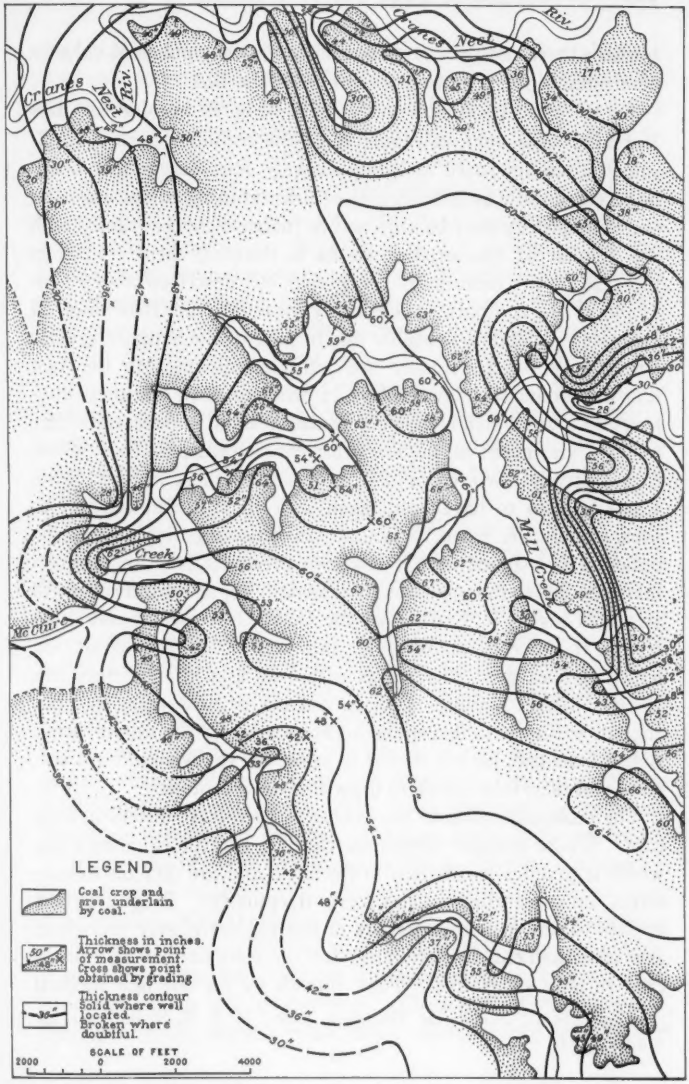
The bed on which thickness contours are drawn is supposed to be the Upper Banner coal bed in the Norton formation of the Pottsville group (Carboniferous).

Because of the great length of outcrop and the numerous measurements of the coal bed available it has been possible in the greater part of the area shown to construct the thickness contours with more than ordinary confidence. Isopachous lines at six inch intervals are shown representing thicknesses from 30 to 66 inches. The bed evidently is very much more irregular than either of these shown preceding (Plates XVI. and XVII.). Such abrupt changes in thickness as are indicated around the 30-inch measurement near Cranes Nest River and between Mill and McClure creeks may be the result of channelling. The noteworthy thing about this example is the striking resemblance of the thickness contours to a rounded type of topography. To accentuate this the contours on Plate XVIII. have been drawn in heavy lines and the other features in lighter lines.

VALUE OF THICKNESS CONTOURS.

Economic Value.—In the first two of the three cases given above the field conditions are perhaps uncommonly favorable for gathering data, and in some fields exposures are too poor to admit of the use of contours. Even where only a few measurements are available, however, it is the experience of the writers that it is highly desirable to take all of them into account in determining the workable limits of the lens. Where data are insufficient to allow of using contours with a view to estimating

[1] Stone, R. W., "Coal Resources of the Russell Fork Basin in Kentucky and Virginia," U. S. Geol. Survey Bull. 348, 1908.


Cranes Nest Riv.
Cranes Nest Riv.
McClure
Mill Creek
LEGEND
Coal crop and area underlain by coal.
Thickness in inches. Arrow shows point of measurement. Cross shows point obtained by grading
Thickness contour solid where well located. Broken where doubtful.
SCALE OF FEET
2000 0 2000 4000

Thickness contours on Upper Banner coal bed, Russel Fork coal field, Dickinson Co., W. Va.

tonnage therefore the contours still have a very practical value in determining or suggesting the limits of the bed.

On the other hand, however, it must be borne in mind that few lenticular beds vary as regularly as the contours seem to indicate. Contours based on comparatively few measurements can be accepted only as indicating the thickness in a general way, and their complexity may be expected to increase concomitantly with the number of measurements used in drawing them. Thus in the case of the thoroughly prospected bed described above (example 3) the contours are decidedly more intricate than those of example 1. This is probably due in part to the actually greater irregularity of the former bed but certainly also to the fact that more data were available. In order to draw thickness contours on a bed which is irregularly channeled it is necessary either to have an enormous number of measurements, or else, where comparatively few are available, to disregard those measurements which happen to have been taken in a channel and attempt to show merely the broad variation. In general geologic work the difficulty occasioned by too few measurements is more common than that due to too many, but occasionally the latter difficulty will arise. Thus F. R. Clarke,[1] of the U. S. Geological Survey, describes the case of an irregular bed near Thompson, Utah, on which he measured 26 sections within an area of less than two square miles. Having no data outside of this area and not enough within it to determine accurately all of the minor variations of the bed, he was unable to select the really significant sections and therefore unable to draw thickness contours.

The economic value of the contours, therefore, differs in each case. Under ordinary conditions they are of little value on a bed which is practically constant in thickness and are difficult to construct on one which varies very irregularly. They are best applied to beds which vary more or less regularly, even though so few measurements are available that the contours can be considered as only suggestive. They furnish by far the best method

[1] Clarke, F. R., "Coal near Thompson, Utah," U. S. G. S. Bull. 541, pp. 453-477, 1914.

of estimating the tonnage and are also of distinct value when the problem is merely to determine the workable limit of the bed without regard to its thickness elsewhere. Finally, it is believed that in ordinary nontechnical descriptions of coal beds the use of thickness contours where possible will save much obscure, verbal description, and that they form a method of graphic presentation sufficiently clear and simple to appeal to the general reader.

Scientific Value.—Our knowledge of the conditions of coal formation and deposition is not as yet sufficiently full to allow of generalizations on the basis of thickness contours. As a means of summing up data for a detailed study of the bed, however, it is believed that they are almost comparable in value to structural contours in a study of oil accumulation. By their construction thickness variations that are practically hidden by the ordinary methods of plotting data are strikingly brought out, and in no other way can so adequate an idea of the general habit of the bed be obtained.

Furthermore, the conviction is almost irresistible that there is some relation between thickness contours of the coal bed and topographic contours of the old surface upon which it formed, but there are many difficulties in the way of exactly determining this relation. In the case of a clean bed unbroken by partings, the top of which is a plane, it is evident that thickness contours are (with the exceptions noted below) equivalent to the topographic contours of the old swamp. Where the top of the bed is not a plane, however, as would be the case where plant growth ceased in one part of the swamp before another, this equivalence would not hold. The exact value of the contours, therefore, depends on whether the datum plane is the top or the bottom of the bed, and in most cases this is difficult or impossible to ascertain. Again, if plant growth is more rapid in one place than another, if local erosion or channelling of the bed took place after deposition, or if the bed was not formed in a normal swamp, it is evident that the thickness contours would not be an exact measure of the old topography. These exceptions, however, destroy only the exact or quantitative relation; they do not affect

the general or qualitative relation. Thus if the thickness contours are all roughly circular it is reasonable to assume that the swamp was of the same general shape. In any case the exact topography of a particular swamp is of little interest except locally, but it is believed that the physiographic clues which these lines furnish, when considered over a broad area, may prove helpful in reconstructing the conditions under which great masses of strata were laid down.

It is evident, however, that in a scientific study of the bed itself the partings must be taken into account, and that the economic method of standardizing sections, which involves deducting not only the thickness of the partings but also an equivalent amount of coal, is entirely misleading. In many cases the partings themselves may be disregarded and the contours drawn on the total coal; in others the total thickness of the bed may best be used, and in some cases it may be advisable to draw two sets of contours, one on the total coal and the other on the total partings The factor on which to base the contours depends entirely on local conditions; in some places the variation is chiefly in the thickness of the partings, while in others it is chiefly in that of the coal itself. In general, however, the partings are more irregular and inconstant than the coal and inasmuch as they do not have the same significance they should not be given the same weight in drawing contours. It is well known, for example, that a foot of coal represents many feet of vegetable matter or even peat, whereas a foot of shale parting represents little more than a foot of mud. Thus in example 3 given above an attempt was made to draw contours on the total thickness of the bed but it was found that the partings vary so irregularly that most of the broad variation in the thickness of coal itself was masked and that the resulting diagram seemed meaningless.

Owing to the variation as to the thickness of the partings, irregularity of the upper and lower surface, bifurcation, etc., which any bed may exhibit, it is impossible to lay down in advance any broad rule for the use of thickness contours in a scientific study. The manner in which they should be applied depends upon the

results desired, and it is believed that their value is sufficiently broad to admit of their use in many ways.

SUMMARY.

Thickness contours as here discussed are imaginary lines connecting points at which a coal bed is of equal thickness. They are best applied to flat-lying or slightly-dipping beds, which vary in thickness in more or less regular manner. Their construction demands a considerable number of sections of the bed, preferably distributed at regular intervals along a sinuous outcrop. The process of drawing them is entirely similar to that of drawing structure contours or of constructing a topographic map from level and transit notes. Partings in the coal bed may be allowed for in several ways; the economic method here suggested is to deduct twice the thickness of the parting from the total thickness of the bed. Thickness contours are of great value in estimating the tonnage of a coal bed, and also in merely attempting to determine its extent. They are helpful in a general scientific study of the bed, and are related in a general way to the topography of the old surface on which it formed. Finally it is believed that they may be used to advantage in geologic reports on coal fields, for they sum up all available thickness data and obviate much verbal description.

ON THE COMPOSITION AND QUALITIES OF COAL.[1]

EDWARD C. JEFFREY.

Some years ago, Dr. David White, chief geologist of the United States Geological Survey, described in this journal the status of the subject of the composition and mode of formation of coal. Since that account was written a great change has been brought about in our views by the new information derived through improved methods of examining coal in thin sections.

The procedure ordinarily employed with success by the mineralogist and petrologist for the study of rocks is only moderately successful when applied to coals. If the sections are ground thin enough to show the coal as a transparent or translucent film, the substance has suffered so by abrasion, that its organization is hopelessly confused. Rénault called attention to these difficulties in his magnificent memoir on the structure of coal published fifteen years ago. He went further than any other investigator, with the methods then available, and on the whole his views in regard to coal were more accurate than those of any other investigator before or since. The present writer has devoted a good deal of attention to devising modifications of paleobotanical and anatomical technique, which would make possible the securing of numerous thin and smooth sections of all categories of coal. Some account of these methods has been published in an article devoted to the study of supposed algal coals.[2] They have been greatly improved in the interval, but have become so complicated by the necessities arising with the various categories of coal, that a separate article is necessary for their description. The present account is written at the invitation of the editors of ECONOMIC GEOLOGY and will deal with the general subject of

[1] Contribution from the Phanerorganic Laboratories of Harvard University. No. 64.

[2] "The Nature of Some Supposed Algal Coals," *Am. Acad. Arts and Sci.*, Vol. 46, No. 12, December, 1910.

the organization of coal as revealed by the microscope with the aid of a new technique for securing thin sections.

It is now very generally recognized that coal is practically entirely of vegetable origin and as a preliminary to its study some brief account must be given of actual vegetable deposits, which in one way or another correspond, or have been considered to correspond to the mother substance of coal. Vegetable matter accumulates in two ways, either in peat bogs as the result of the heaping up of the remains of successive generations of plants in successive layers, or in lakes or lagoons, as floated material which has gradually sunk to the bottom. Both methods of accumulation are commonly found in the present epoch in temperate climates; but only the second manner of accumulation is of importance within the tropics. Vegetable material is commonly found in the bottoms of tropical lakes, where the conditions are favorable for accumulation, but nothing really corresponding to a peat bog of the northern hemisphere has yet been discovered in the regions lying near the equator. The two methods of accumulation briefly described have both been used to elucidate the formation of coal deposits and for nearly a hundred years geologists have divided in favor of the opposite views. The peat bog hypothesis, or growth *in situ* (autocthonous) hypothesis, at the present moment has won the adhesion of the majority of geologists, although it encounters the serious difficulty that peat bogs are not found in the parts of the earth which at the present time present the nearest approach to the conditions of climate obtaining in the great coal-forming epochs. The lacustrine or transport (allocthonous) hypothesis, which is better applicable to the conditions of warmth which are generally conceded to have existed in the most active periods of coal formation, has had few adherents in recent years outside France. It is however the hypothesis which harmonizes best with the structures found in coals, as the result of microscopic examination. The present article will not deal particularly however with the subject of the mode of coal formation.

The bottom of a modern lake which is not too wind swept, too

EXPLANATION TO PLATE XIX.

FIG. 151. Showing the composition of fine lacustrine muck in which are mingled pollen grains of the pine, the spruce and the fir.

FIG. 152. The organization of shallow water accumulations in a lake of the present epoch, showing remains of roots, leaves, etc. Near the center of the figure is to be seen the triangular needle of a white pine.

FIG. 153. Section of English Coal Ball or concretion representing an accumulation in a modern lake.

FIG. 154. Section of a concretion from Westphalia showing small calamite stem, flattened by pressure.

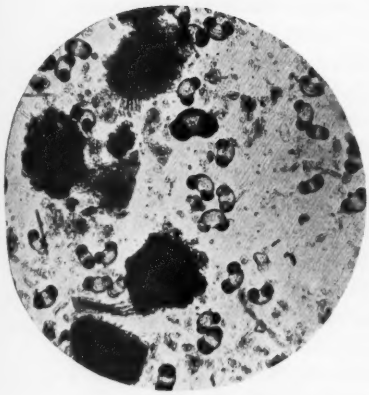


FIG. 151.

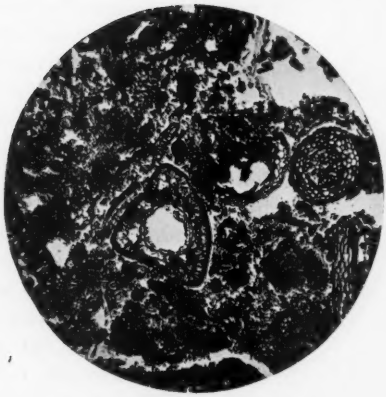


FIG. 152.

FIG. 153.

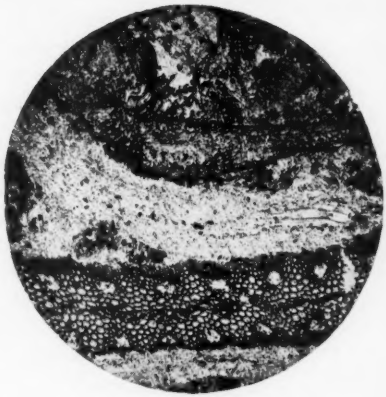


FIG. 154.

inconstant in level or too much devastated by floods, gradually accumulates vegetable matter, swept in by the breezes from the air, or washed by the rains from the forest floor. In the deeper and stiller parts, the vegetable material forms a fine muck and where the water is more shallow, the vegetable deposits are of coarser nature. The shallows are with now increasing rapidity of accumulation, sooner or later transformed into bog, which finally becomes firm enough to support the weight of a forest of trees. Fig. 151 illustrates the composition of a fine lacustrine muck. There are present certain masses of irregular outline, the excrement balls of fishes, snails or amphibia, mingled with these are numerous pollen grains of the pine, the spruce and the fir, which appear as clear structures with pairs of darker seeming appendages, the air chambers or wings, which serve to float the grains through the atmosphere, to a chance union with a seed, seldom realized. The bottom of every lake is filled with countless pollen grains or spores. As the bottom becomes shallower, waterlilies and other water plants make their appearance and add their remains to the lacustrine accumulations. Finally the coarser débris of land plants is added to the heap and not long afterwards mosses, grasses, sedges, heaths and ultimately forest trees, may flourish, where once was open water. Fig. 152 makes clear the organization of the shallow water accumulations in a lake of the present epoch. The sample was taken from the north beyond the present range of the white pine, yet near the center of the figure is to be seen the triangular needle of a white pine, thus indicating an earlier different distribution of this species. Round about lie remains of roots, leaves and other less recognizable vegetable flotsam and jetsam.

Our views of the organization of coal have in the past, on account of the technical difficulties described in the first paragraph, been based upon certain isolated data. The most important information in regard to the flora of the coal period proper has been derived from certain concretions, characteristic of coal beds supposedly of maritime or paralic origin. Beds of this type occur in Yorkshire and Lancashire in England, in Westphalia in

Germany and in portions of the great Donetz coal field of European Russia, as well as in other regions less important or less well known. Fig. 153 shows a section of an English coal ball or concretion. It is readily seen that the substance present is of the same general character as that shown in Fig. 152 representing an accumulation in a modern lake. Fig. 154 illustrates a similar concretion from Westphalia, which I owe to the kindness of the Geologische Landesanstalt of Prussia. The most clearly recognizable structure is a small calamite stem, flattened out by pressure. Fig. 155 shows the structure of the coal surrounding a coal ball or concretion in Westphalian coal. All organization is obviously gone, a condition which is observed generally in coals derived from ordinary vegetables débris, however accumulated. Fig. 156, a cretaceous coal from the western states, shows a common condition, where wood structure is partially preserved. In all such cases the wood was partially or completely transformed into charcoal, before it was incorporated into the accumulation, later transformed into coal. Carbonized wood is in fact the only material derived from the grosser parts of plant bodies,

FIG. 157. Longitudinal view of mother of coal or carbonized wood. From a Jurassic coal from Brora in Scotland.

which retains its structure in coal. It is generally designated mineral charcoal or mother of coal, and may be present in all categories of coal, from cannels to anthracites. Fig. 157 shows a longitudinal view of mother of coal, or carbonized wood from a Jurassic coal from Brora in Scotland. The wood structure is very clearly revealed, not only in the fibers but also in the silver grain or rays. Fig. 158 shows a section of Illinois carboniferous coal. The dark stripe running a little above the center is mother of coal or mineral charcoal. The rest of the coal substance is made up of paler and darker stripes, the former constituting the bright bands or "glance" of the gross aspect of the coal and the latter the "matt" of the macroscopic view.

It will be convenient now to turn our attention to a quite different category of coals. Fig. 159 illustrates the structure of tasmanite, a Paleozoic carbonaceous deposit of Tasmania. This is an almost pure spore coal. Above the center can be made out a spore still uncollapsed and a little below it on the left another which has only partially collapsed. The rest of the spore material seen in the figure consists of spores which have collapsed so that their original spherical central cavity is represented by a linear chink in the flattened spore. Fig. 160 shows the organization of another richly sporiferous coal. Here the spores are very thick-walled and rough, a condition which has led to considerable confusion as regards their identification. Until quite recently these bodies present in typical oilshales or bogheads have been regarded as the remains of gelatinous Algæ, the most delicate and perishable of all organisms. The improved methods referred to in the first paragraph have however made clear that they are in reality thick-walled spores of lower fernlike plants. Fig. 161 shows clear evidence as to the nature of such bodies in coal. On the left appears one of them with a triangular ridge on the face of it, similar to that found on the ventral surface of the spores of many fernlike plants of the present epoch, to the right is a group of spores, three of these showing at once, and furnishing the final evidence that the bodies in question are spores and not such delicate structures as Algæ. In fact the

EXPLANATION TO PLATE XX.

FIG. 155. Structure of the coal surrounding a coal ball in Westphalian coal.

FIG. 156. A cretaceous coal from the western states showing partial preservation of wood structure.

FIG. 158. Section of Illinois carboniferous coal. The dark stripe above the center is mother of coal or mineral charcoal.

FIG. 159. Showing the structure of tasmanite, a Paleozoic carbonaceous deposit of Tasmania. Above the center can be made out a spore still uncollapsed and below it one which has only partially collapsed.

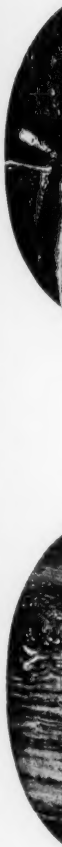


FIG. 155.

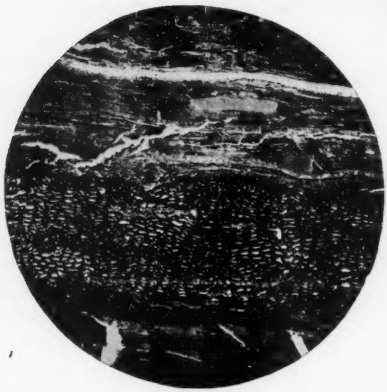


FIG. 156.

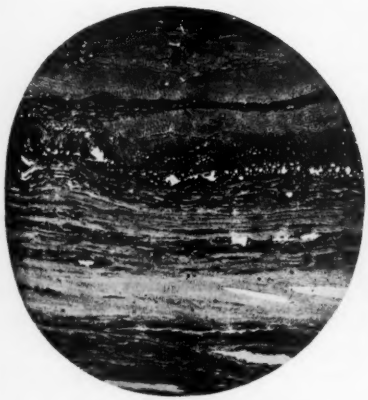


FIG. 158.

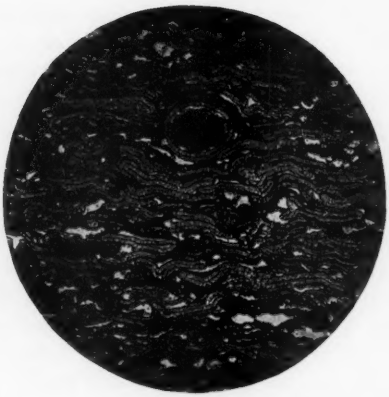


FIG. 159.

common occurrence of highly modified remains of wood side by side with the supposed Algæ in coal completely negatives the possibility of their being anything of so delicate a nature. In contrast to Algæ, spores are the most resistant of vegetable remains, and they are usually recognizable in coals even of the highest grade, in which the vegetable constituents have undergone the greatest degree of modification.

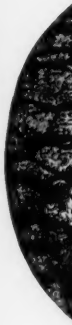
The next illustration shows the organization of a well-recognized category of coals, namely the cannels. Fig. 162 shows the composition of a coal of this type, the light bodies are collapsed spores, the crinkled bands of somewhat darker hue represent remains of wood, much modified. In addition to these is the dark ground substance, which is always present in canneloid and boghead coals. Fig. 163 shows part of the field of Fig. 162 considerably more highly magnified. Certain of the spores are now more clearly recognizable. In Fig. 164 is shown a horizontal view of the same cannel. In this aspect the spores appear as round light bodies. These three illustrations represent cannel coal from Kentucky.

The coals figured in illustrations 159–164, inclusive, represent coals, which are admitted in all competent quarters to have been formed under open water conditions, in other words to be constituted of the muck of the bottoms of ancient lakes or lagoons. We may now turn our attention to the commoner and more abundant coals, since cannels and bogheads constitute a very small proportion (probably less than five per cent. of all the coals mined). And it is precisely concerning these abundant coals, that our knowledge in the past has been deficient, as for the most part they have given up little information as to their structural composition when examined by the ordinary methods employed in the microscopic study of minerals. The improvement in technique mentioned above has however made it possible to secure transparent sections of coals of this type and as a consequence we are now in a position to know their minute organization and to draw inferences as to their original constituents and the manner in which they were laid down. Fig. 165 illustrates

EXPLANATION TO PLATE XXI.

FIG. 160. Showing the organization of a richly sporiferous coal.
FIG. 161. Showing thick-walled spores of lower fernlike plants.
FIG. 162. Showing the composition of cannel coal. Crinkled bands represent the remnants of wood.
FIG. 163. Showing a part of figure 889 highly magnified.

PLATE XXI.



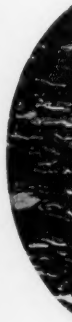


FIG. 160.

FIG. 161.

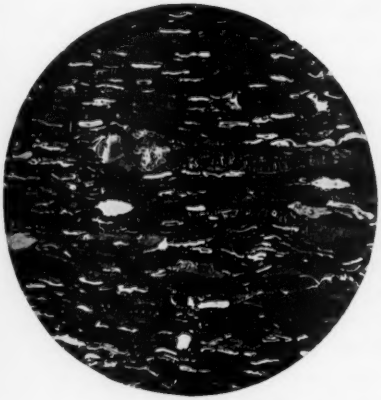


FIG. 162.

FIG. 163.

the intimate structure of a thin section of highly bituminous coal from Kentucky. The coal is crossed from side to side by more or less crinkled bands, which represent masses of woody substance, which has entirely lost its original organization. The crinkled appearance is due to a double cause, first the lignitoid or woody substance of the coal tends to crack and second being more resistant to the knife than the rest of the coal is more or less thrust up in the operation of cutting the section. The lignitoid bands shown in the photograph appear as very fine shining lines or laminæ in the gross specimen of coal under discussion. In most coals the lignitoid laminæ are much coarser than in that being described and are consequently much less suitable for microscopic illustration. Between the lignitoid or shining layers are strata in the coal, which appear darker, on the whole, in the illustration and duller in the hand specimen. These are the canneloid layers of the coal. The two kinds of layers are of course generally known in descriptive terminology as glance coal and matt coal. Fig. 166 shows a portion of the same coal much more highly magnified. The lignitoid (glance) and canneloid (matt) layers are now decipherable in detail. Obviously the matt or canneloid consists of a dark ground substance like that or ordinary cannel in which are embedded the remains of flattened spores. Several of the spores in the illustration are quite large in size and are consequently clearly recognizable. The rest although much more abundant can less easily be made out. In contrast to the canneloid portions of the coal, the lignitoid layers are quite homogeneous, that is they have entirely lost their original structure.

The type of coal figured in illustrations 165 and 166 is relatively uncommon. Usually the lignitoid substance is much more abundant than the canneloid, in ordinary bituminous and anthracitic coals, and they reveal this increased proportion of woody substance in their glistening aspect when viewed as gross specimens. Even in the brightest coals however microscopic examination with improved methods reveals canneloid material. When the latter substance is very scanty it cannot be determined at all by

EXPLANATION TO PLATE XXII.

FIG. 164. A horizontal view of cannel shown in Fig. 162.

FIG. 165. Intimate structure of a thin section of highly bituminous coal from Kentucky showing crinkled bands which represent masses of woody substance.

FIG. 166. A portion of Fig. 165 highly magnified. The lignitoid and canneloid layers are now decipherable in detail.

FIG. 167. A typical lean non-coking coal from the Indiana coal fields.

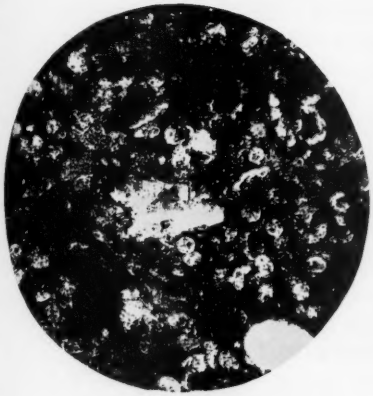


FIG. 164.

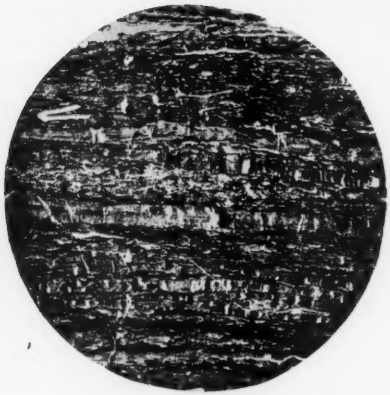


FIG. 165.

FIG. 166.

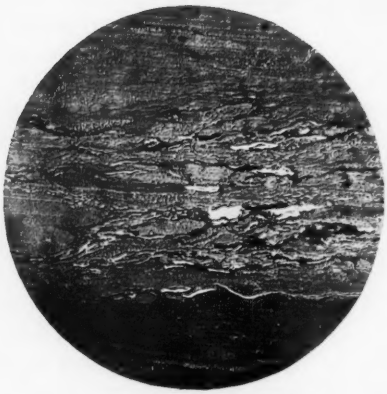


FIG. 167.

gross examination. Fig. 167 shows the organization of a coal of this organization. This is a typical lean non-coking coal from the Indiana coal fields. In spite of the fact that this coal appeared entirely glance-like to the eye, its microscopic structure reveals the presence of spores or canneloid material, as may be seen by examining the figure. In the center is a faintly canneloid layer, above and below which the coal appears purely lignitoid.

We have purposely chosen extremes of bituminous coals for illustration. The mass of coals may be described as lying between the extremes shown in the illustrations and as consequently composed of more canneloid than that shown in Fig. 167 and less than in illustrations 165 and 166.

It will be seen from the various illustrations that coals may be composed of three recognizable constituents, namely spores or canneloid, modified wood or lignitoid and less commonly in most cases of relatively unmodified carbonized wood or mineral charcoal (mother of coal of authors). It may be added that the statements made here depend on the examination by improved methods of a much larger number of coals from different geological ages and remote geographical areas, than have hitherto been investigated. Coals from all levels from the Devonian to the Miocene have been examined and from every coal-producing part of the world except South Africa. It further appears clear that the properties of coal depend to a very large degree on the proportions of their original constituents. Coals rich in spores such as cannels, bogheads and oil shales are petroliferous or highly bituminous and in some form or other are the mother substance of oil and gas, whether occurring naturally or distilled by the artifice of man. The spore content of a coal, other things being equal, determines its fatness or bituminosity and in all probability has a definite relation to its availability for coking purposes in connection with metallurgical processes. It is likewise not unlikely that the spore content of a coal has some relation to the degree of explosibility of the atmosphere or of the mine dust of the mine where it is worked. The lignitoid constituents

of coal by their presence in greater degree reduce the bituminosity and coking value of the coal. It is not clear that the presence of mother of coal in quantity in coals has any other effect than that of increasing the carbon ratio in coals of natural low grade. The grade of a coal, that is its proportion of carbon, appears to depend to a very slight degree however on the nature of its original constituents and much more on the events which have taken place after the raw material of the coal is deposited. It seems likely however, so far as these studies have yet been prosecuted, that a high degree of spore content will reduce the chances of a coal being ultimately transformed into anthracite.

A method having been devised for the more successful investigation of coal, it now appears highly advisable that careful studies should be carried on as to the variation of microscopical structure in coal seams vertically and horizontally, the relation of microscopical structure to qualities and grade, as well as to liability to form explosive dusts and gases.

The present statement is a brief digest of studies on coal which have been carried on for the past seven years. Special articles dealing with the various types of coal and the conditions of coal formation will be published from time to time, as the work progresses. The writer has received through the kindness of the Geological Surveys and other geological establishments and organizations of various parts of the world a large and increasing amount of material, which will later perhaps serve as the basis of a book devoted to the subject of the composition, organization and mode of formation of coal. Contributions of specimens of coal are invited and all assistance furnished in this direction will be acknowledged in the special articles as they appear. Another general article on the conditions of formation of coal is in preparation and will be published elsewhere.

Botanical Laboratories of Harvard University.

THE RATE OF REDUCTION OF ACIDITY OF DESCENDING WATERS BY CERTAIN ORE AND GANGUE MINERALS AND ITS BEARING UPON SECONDARY SULPHIDE ENRICHMENT.[1]

G. S. NISHIHARA.

INTRODUCTION.

Since the announcement of the theory of secondary sulphide enrichment by S. F. Emmons,[2] W. H. Weed,[3] and C. R. Van Hise[4] in 1900 there has been an increasing interest shown in the chemistry and physics of the process involved. A summary of the process of enrichment of copper deposits by J. F. Kemp[5] appeared in 1906 and the criteria of downward sulphide enrichment were reviewed by F. L. Ransome[6] in 1910. An important study of sulphides was made in 1888 by Schuerman,[7] and was followed by the contributions of many others.[8]

[1] A thesis submitted in partial fulfillment of requirements for the M.S. degree at the University of Minnesota.

[2] Emmons, S. F., "The Secondary Enrichment of Ore Deposits," *Trans. Amer. Inst. Min. Eng.*, Vol. 30, 1900, pp. 117–217.

[3] Weed, W. H., "The Enrichment of Gold and Silver Veins," *Trans. Amer. Inst. Min. Eng.*, Vol. 30, 1900, pp. 424–448.

[4] Van Hise, C. R., "Some Principles Controlling the Deposition of Ores," *Trans. Amer. Inst. Min. Eng.*, Vol. 30, 1900, pp. 27–177.

[5] Kemp, J. F., "Secondary Enrichment in Ore Deposits of Copper," ECON. GEOL., Vol. 1, 1906, pp. 11–12.

[6] Ransome, F. L., "Criteria of Downward Sulphide Enrichment," ECON. GEOL., Vol. 5, 1910, p. 205.

[7] Schuerman, E., Über die Verwandtschaft der Schwermetalle zum Schwefel," *Liebigs Ann. der Chemie*, Vol. 249, 1888, p. 326.

[8] Wiegel, O., "Das Löslichkeit von Schwermetallesulfiden in reinem Wasser," *Zeitsc. physik. Chemie*, Vol. 58, 1907, pp. 293–300. Wells, R. C., "The Fractional Precipitation of Sulphides," ECON. GEOL., Vol. 5, 1910, pp. 1–14. Winchell, H. V., "Synthesis of Chalcocite and Its Genesis at Butte, Montana," *Bull. Geol. Soc. Amer.*, Vol. 14, 1903, pp. 269–276. Sullivan, E. C., "Interaction of Minerals and Water Solutions," Bull. U. S. G. S., No. 312. Read, T.

In the earlier papers on this subject much emphasis was placed upon the permeability of the deposits as controlling the depth at which precipitation goes on. It is known, however, that certain minerals react on the solution to precipitate the metals much more rapidly than others, and that the chemical and mineralogical composition as well as the permeability of the deposits is important.

Analyses of mine waters in the sulphide ore deposits show considerable differences as to acidity and state of oxidation, but they are essentially acid sulphate solutions of metals, alkalies and alkaline earth and in depth the acidity gradually decreases until they become neutral or slightly alkaline. The following experiments were undertaken with a view to ascertaining the rate at which various minerals react with and reduce the acidity of solutions like those that are commonly supposed to be active in sulphide enrichment.

SERIES I. EXPERIMENTS WITH H_2SO_4

Carefully selected specimens of primary sulphides and gangue minerals common to sulphide ore deposits were crushed in three sizes, and taken in samples of one and five grams. The first size was that passed through No. 20 mesh and caught on No. 80 mesh screen; the second size, passed through No. 80 mesh and caught on No. 200 mesh screen; the third size, passed through No. 200 mesh screen. Thirty cubic centimeters of 1/8 normal sulphuric acid was added and the bottles were corked but no other precautions were taken against oxidation. The acidity of the solutions was tested by taking out two cubic centimeters of the extract and titrating against tenth normal sodium carbonate at several intervals. The relative activity of minerals in reducing acidity is shown in the following table:

T., "Secondary Enrichment of Copper and Iron Sulphides," *Trans. Amer. Inst. Min. Eng.*, Vol. 37, 1907, p. 300.

Allen, E. T., Crenshaw, J. L., and Johnston, J., *Amer. Jour. Sci.*, Vol. 33, March, 1912. Stokes, H. N., "The Action of Solutions on Pyrite and Marcasite," ECON. GEOL., Vol. 2, 1907, p. 22. Buehler and Gottchalk, "The Oxidation of Sulphides," ECON. GEOL., Vol. 5, p. 28, and Vol. 7, p. 15. Winchell, A. N., "The Oxidation of Pyrite," ECON. GEOL., Vol. 2, p. 290. Grout, F. F., "The Oxidation of Pyrite," ECON. GEOL., Vol. 3, p. 532.

TABLE I.

RELATIVE ACTIVITY OF MINERALS IN DECREASING ACIDITY OF N/8 H_2SO_4.
(2.5 c.c. indicates no action.)

Minerals in Order of Activity.	1 Day.	1 Week.	2 Weeks.	3 Weeks.	1 Month.	2 Months.	3 Months.
Calcite	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Rhodochrosite	0.1	0.0	0.0	0.0	0.0	0.0	0.0
Siderite	2.0	0.3	0.0	0.0	0.0	0.0	0.0
Nephelite	1.9	0.6	0.2	0.1	0.0	0.0	0.0
Pyrrhotite	2.2[1]	1.1[1]	0.6[1]	0.1[2]	0.0	0.0	0.0
Leucite	1.2	1.0	0.8	0.6	0.4	0.3	0.3
Tetrahedrite	2.3	1.9	1.7	1.6	1.5	1.4	1.1
Labradorite	2.3	2.3	2.0	2.0	1.9	1.6	1.3
Hornblende	2.3	2.3	2.1	2.1	1.9	1.8	1.4
Galena	2.5[1]	2.5[1]	2.4[1]	2.4[1]	2.3[1]	1.9[1]	1.4[1]
Augite	2.4	2.3	2.2	2.2	2.2	1.7	1.6
Sphalerite	2.5[1]	2.5[1]	2.5[1]	2.5[1]	2.4[1]	2.3[1]	2.1[1]
Biotite	2.4	2.4	2.3	2.3	2.3	2.2	2.2
Fluorite	2.5	2.5	2.5	2.5	2.5	2.4[3]	2.3
Orthoclase	2.5	2.5	2.4	2.4	2.4	2.4	2.3
Chalcopyrite	2.5	2.5	2.5	2.4	2.4	2.4	2.4
Arsenopyrite	2.5	2.5	2.5	2.5	2.5	2.5	2.4
Marcasite	2.5	2.5	2.5	2.5	2.5	2.5	2.5
Muscovite	2.5	2.5	2.5	2.5	2.5	2.5	2.5
Pyrite	2.5	2.5	2.5	2.5	2.5	2.5	2.5
Quartz	2.5	2.5	2.5	2.5	2.5	2.5	2.5

Minerals one gram, 80–200 mesh in 30 c.c. acid solution. 2 c.c. extract was titrated against N/10 Na_2CO_3 in each test. Figures indicate the c.c. Na_2CO_3 used in titration.

Considerable difficulty was experienced in securing sufficiently pure specimens, and in some there were more or less impurities present. The chalcopyrite was so contaminated with calcite that it had to be separated in heavy solution and by the subsequent digestion with dilute acid.

As might be expected the difference in size of grains affected the reducing activities more markedly than different quantities taken or length of time as it is shown in the table next following.

The reduction of acidity by carbonates was rapid. Among sulphides pyrrhotite was the most active and was as active as some of the carbonates. Among silicates leucite and nephelite were strikingly active.

[1] H_2S odor.
[2] H_2S odor very slight.
[3] White needles of gypsum(?) formed.

	Labradorite 1 gram.			Labradorite 5 grams.		
	20-80.	80-200.	200+.	20-80.	80-200.	200+.
1 day	2.4	2.3	2.2	2.2	2.0	1.7
1 week	2.4	2.3	2.0	1.8	1.8	1.1
2 weeks	2.2	2.0	1.8	1.6	1.2	0.5
3 weeks	2.2	2.0	1.6	1.5	1.1	0.3
1 month	2.1	1.9	1.6	1.0	0.8	0.2
2 months	1.8	1.6	1.1	0.8	0.5	0.1
3 months	1.7	1.3	1.0	0.6	0.3	0.0

As soon as the neutral point was reached there was no indication of further change toward either alkalinity or acidity. According to Kengott[1] and Cornu,[2] apatite, aragonite, calcite, dolomite, feldspars, magnetite, micas, nephelite, olivine, pyroxenes, serpentine, siderite, spodumine, talc, and tourmaline give alkaline reactions to litmus or phenolphthalein, and it was possible that some alkalies have been contributed to the solution in the experiment herein described, but the amount was too small to have affected the solution greatly.

With some minerals activity varied with the length of time.[3] Leucite, for example, was at the beginning more active, but later became less active than pyrrhotite. Initial and persistent activities are, therefore, important factors to be considered.

During the experiments it was noticed that, besides pyrrhotite and sphalerite, the galena and some marcasite also evolved hydrogen sulphide gas copiously and galena reduced acidity with unexpected rapidity. A chemical analysis revealed the presence of manganese, probably as sulphide. As much as 0.04 per cent. of manganese was found in a cube of apparently pure galena. Lead and zinc ores from Wisconsin, and argentiferous galena from several mining districts in California, Nevada, Montana,

[1] Kengott, Neues Jahrbuch, 1867, p. 302.

[2] Cornu, F., *Tsch. Mitteilung*, Vol. 24, 417–32, a25, 489.

[3] Bard, D. C., Econ. Geol., Vol. 5, p. 59. Cooke, H. C., "Secondary Enrichment of Silver Ores," *Jour. Geol.*, Vol. 21, p. 1. Brokaw, A. D., "The Solution of Gold in the Surface Alteration of Ore Bodies," *Jour. Geol.*, Vol. 18, p. 322. Emmons, W. H., Bull. U. S. G. S., No. 529. Grout, F. F., Econ. Geol., Vol. 8, p. 407. Graton, L. C., and Murdock, J., "The Sulphide Ores of Copper," *Trans. Amer. Inst. Min. Eng.*, Vol. 4, p. 754.

Colorado, and Spain were analyzed and were found to contain more or less manganese almost certainly as sulphide. The argentiferous galena from Idaho Springs, Colorado, gave 0.12 per cent. of manganese. Several marcasites of radiating structure contained nearly 0.1 per cent., others were apparently free from manganese. Pyrrhotite and sphalerite were also analyzed, but there was no trace of manganese. A print made on a lead acetate paper from a polished surface of galena after an application of dilute acid showed large areas of equal darkness suggesting an exceedingly intimate mixture of galena and alabandite. Both galena and alabandite belong to the same crystallographic system, and might form an isomorphous mixture.

SERIES 2. EXPERIMENTS WITH FERRIC SULPHATE SOLUTION.

The decrease of ferric sulphate in mine waters with depth suggests that ferric sulphate has been reduced.[1] In order to determine relative activities of minerals in reducing ferric sulphate a second series of experiments was made. The minerals were treated with ferric sulphate solution, tenth normal with respect to iron, and tested for acidity with tenth normal sodium carbonate and for amount of reduced iron with potassium permanganate solution, one c.c. of which was equivalent to 0.0016 gram of FeO. The order of activity in reducing iron agrees fairly well with that determined by Grout[2] with a few exceptions. Tables II. and III. show the relative activities of minerals in reducing ferric sulphate solutions.

As shown in the Tables II. and III. the reduction of acidity is in general nearly proportional to the amount of iron reduced. Pyrrhotite and siderite, however, not only reduced acidity, but they also supplied ferrous iron.

Comparing Tables I. and II. it may be noted that arsenopyrite and pyrite are more active on ferric sulphate than on sulphuric acid.

[1] Emmons, W. H., U. S. G. S. Bull. No. 529. Emmons, W. H., and Harrington, G. L., ECON. GEOL., Vol. 8, p. 653.

[2] Grout, F. F., ECON. GEOL., Vol. 8, p. 417.

TABLE II.

RELATIVE ACTIVITIES OF MINERALS IN REDUCING ACIDITY OF FERRIC SULPHATE, TENTH NORMAL WITH RESPECT TO IRON.

Minerals in Order of Activity.	1 Day.	2 Days.	3 Days.	5 Days.	7 Days.
Calcite	0.1	0.0	0.0	0.0	0.0
Olivine	2.4	2.0	1.5	1.1	0.0
Sodalite	1.8	1.4	0.8	0.2	0.1
Rhodochrosite	2.4	2.1	1.6	0.8	0.2
Siderite	2.6	2.4	2.1	1.4	0.7
Pyrrhotite	2.7	2.4	2.1	1.4	0.8
Leucite	2.5	2.3	2.2	1.9	1.6
Tetrahedrite	2.7	2.6	2.4	2.2	1.7
Galena	2.7	2.6	2.4	2.3	2.0
Arsenopyrite	2.9	2.9	2.8	2.7	2.5
Labradorite	3.0	3.0	2.8	2.7	2.6
Sphalerite	3.0	2.8	2.8	2.7	2.6
Pyrite	3.0	3.0	3.0	2.6	2.6
Hornblende	3.0	2.9	2.9	2.7	2.6
Enargite	3.0	3.0	3.0	2.9	2.6
Marcasite	3.0	3.0	2.9	2.6	2.6
Kaolinite	2.9	2.9	2.8	2.8	2.7
Augite	3.0	2.9	2.9	2.8	2.7
Chalcopyrite	3.0	3.0	3.0	2.8	2.8
Biotite	3.0	3.0	3.0	3.0	2.9
Orthoclase	3.0	3.0	3.0	3.0	3.0
Muscovite	3.0	3.0	3.0	3.0	3.0
Fluorite	3.0	3.0	3.0	3.0	3.0
Quartz	3.0	3.0	3.0	3.0	3.0

Minerals one gram, 80–200 mesh in 30 c.c. ferric sulphate, N/10 with respect to iron. 2 c.c. extract was titrated against N/10 Na_2CO_3 in each test. Figures indicate the c.c. Na_2CO_3 used in titration.

The calcite which was the most active in both series of experiments did not reduce iron, but precipitated it as ferric hydroxide.

As in the series of experiments in sulphuric acid no further change in acidity or alkalinity could be detected after the neutral point had been reached. Moreover the amount of reduced iron remained the same for three months. A quantitative analysis confirmed the supposition that the total iron was combined with SO_4 in the form of $FeSO_4$.

According to Stokes[1] the action of ferric sulphate on pyrite proceeds as follows:

$$Fe_2(SO_4)_3 + FeS_2 = 3FeSO_4 + 2S \text{ and}$$
$$2S + 6Fe_2(SO_4)_3 = 8H_2O + 12FeSO_4 + 8H_2SO_4.$$

[1] Stokes, H. N., ECON. GEOL., Vol. 2, p. 22.

TABLE III.

RELATIVE ACTIVITY OF MINERALS IN REDUCING IRON IN FERRIC SULPHATE SOLUTION, N/10 WITH RESPECT TO IRON.

Minerals in Order of Activity.	1 Day.	2 Days.	3 Days.	5 Days.	7 Days.
Pyrrhotite	0.2	1.2	1.9	3.2	4.3
(Siderite)	0.2	1.0	1.6	2.7	3.8
Tetrahedrite	0.2	0.7	1.2	1.9	2.3
Arsenopyrite	0.3	0.5	0.6	1.2	1.7
Galena	0.6	0.7	1.0	1.2	1.5
Enargite	0.2	0.3	0.5	0.6	1.1
Marcasite	0.2	0.4	0.4	0.8	0.9
Pyrite	0.2	0.3	0.5	0.7	0.8
Sphalerite	0.1	0.3	0.4	—	0.5
(Olivine)	0.0	0.2	0.2	0.3	0.4
Chalcopyrite	0.1	0.2	0.2	0.2	0.3
(Hornblende)	0.0	0.0	0.0	0.1	0.2
Orthoclase	0.0	0.0	0.0	0.0	0.0
Calcite	0.0	0.0	0.0	0.0	0.0
Rhodochrosite	0.0	0.0	0.0	0.0	0.0
Fluorite	0.0	0.0	0.0	0.0	0.0
Labradorite	0.0	0.0	0.0	0.0	0.0
Leucite	0.0	0.0	0.0	0.0	0.0
Muscovite	0.0	0.0	0.0	0.0	0.0
Quartz	0.0	0.0	0.0	0.0	0.0
Sodalite	0.0	0.0	0.0	0.0	0.0
Augite	0.0	0.0	0.0	0.0	0.0
Biotite	0.0	0.0	0.0	0.0	0.0
Kaolinite	0.0	0.0	0.0	0.0	0.0

Minerals one gram, 80–200 mesh in 30 c.c. ferric sulphate, N/10 with respect to iron. 2 c.c. extract was titrated against $KMnO_4$. 1 c.c. = 0.0016 gr. FeO in each test. Figures indicate the c.c. $KMnO_4$ solution used in titration.

This indicates a considerable amount of sulphuric acid is generated. Titration against tenth normal sodium carbonate solution, however, showed a gradual decrease of acidity, and finally the solutions with active sulphides became neutral. With pyrrhotite the solution became neutral at the end of two weeks when evolution of hydrogen sulphide gas ceased and hydroxide of iron had begun to form. A probable reaction in this case may be indicated by the following equation, which was suggested by Professor Grout:

$$Fe_7S_8 + 6Fe_2(SO_4)_3 + H_2SO_4 = H_2S + 19FeSO_4 + 7S.$$

It is known that gypsum and kaolinite are formed by acid solution attacking calcite of limestone and feldspars of igneous rocks. Gypsum and kaolinite are associated with chalcocite at

many places and the inference is plausible that acid is produced by the chalcocite forming process. These experiments described above, however, show that acid sulphate and ferric sulphate reacting on pyrite and several other sulphides may be reduced without generation of acid.

SERIES 3. EXPERIMENTS WITH FERROUS AND CUPRIC SULPHATE SOLUTION.

All the carbonates are active in reducing acidity. Calcite readily precipitates iron and copper out of a mixed solution of ferrous and cupric sulphate. This led D. C. Bard[1] to conclude that calcite gangue would tend to inhibit secondary enrichment of sulphides. There are, however, numerous examples of secondarily enriched sulphide ore bodies in limestones.

Recently A. C. Spencer[2] obtained secondary bornite and other sulphide coating on chalcopyrite in a cupric and ferrous sulphate solution in the presence of calcite, and he suggests that calcite does not inhibit the downward migration of copper, as in his experiment the calcite did not precipitate copper. In a solution even slightly acid bornite is not precipitated on chalcopyrite, and this suggests that the presence of a reducing substance is necessary.

A solution of iron sulphate and copper sulphate was brought simultaneously in contact with calcite and chalcopyrite, and it was found that the calcite precipitated iron as ferric hydroxide and copper as carbonate, and at the same time chalcopyrite was coated with the secondary bornite. When ferric sulphate was introduced the bornite coating was quickly destroyed, but later when the calcite had neutralized ferric sulphate the secondary deposition went on again without interruption. The calcite precipitated the iron as ferric hydroxide and copper as carbonate, as before, and at the same time reduced the acidity of the solution, and the sulphide was deposited as before the introduction of ferric sulphate. In order to ascertain the chemical composition of the coating the following test was made:

[1] Bard, D. C., ECON. GEOL., Vol. 5, p. 5.
[2] Spencer, A. C., ECON. GEOL., Vol. 8, p. 621.

A selected specimen of chalcopyrite was crushed and passed through a No. 20 mesh sieve and caught on a No. 40 mesh sieve and washed with dilute acid to remove any calcite present. After drying, two equal portions of the chalcopyrite were weighed into beakers, and into one of them cupric and ferrous sulphate and

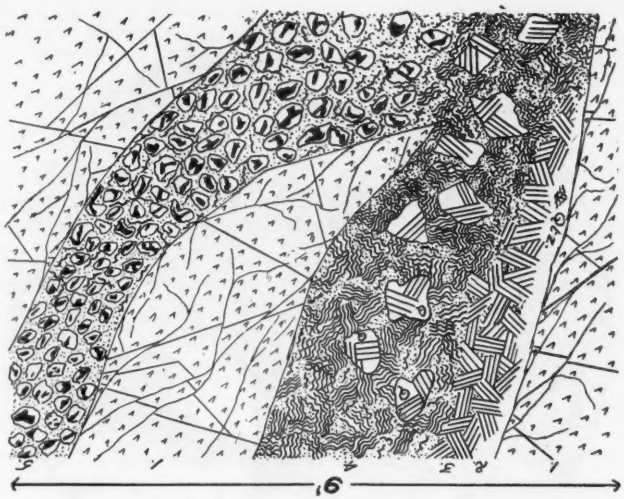


FIG. 168. 1, Altered quartz-monzonite; 2, quartz (*Q*); 3, enargite; 4, covellite-chalcocite; 5, quartz-pyrite, enargite, breccia, cemented with covellite-chalcocite.

calcium carbonate were added. A boiling temperature was employed in order to accelerate the chemical action. When sufficiently tarnished the content was dumped on a No. 40 mesh sieve and washed thoroughly with hot water until the wash water no longer showed copper. The mineral then was treated with a fairly strong hydrochloric acid and the coating was dissolved out. At the same time the same amount of hydrochloric acid was added to the other beaker in which an equal portion of the chalcopyrite had been placed. Some ammonia water was added to

both solutions and brought to boiling to precipitate iron. The equal volumes of solutions were compared for copper contents. The tube containing the solution from the tarnished chalcopyrite had decidedly more copper than that from the chalcopyrite alone. Also the iron precipitate obtained from the mineral treated with

FIG. 169. (× 13 diam.) 1, Silicified quartz-monzonite; 2, enargite; 3, covellite; 4, chalcocite, with some bornite.

cupric and ferrous sulphate solution was more than that from the one that was not treated with acid solution. This showed that the coating was not due to a mere physical change but to a change in chemical composition. Further in connection with this experiment the following results were obtained in hot solutions:

Chalcopyrite and Pyrite in Contact With	Color of Original Mineral.
1. Cupric sulphate	Unchanged.
2. Ferrous sulphate	Unchanged.
3. Ferric sulphate	Unchanged.
4. Cupric and ferric sulphate	Unchanged.
5. Cupric and ferric sulphate and calcite	Unchanged.
6. Cupric sulphate and calcite	Unchanged.
7. Ferrous sulphate and calcite	Unchanged.
8. Cupric sulphate and ferrous sulphate	Tarnished chalcopyrite.
9. Cupric, ferrous and ferric sulphate	Tarnished chalcopyrite, but in a less degree.
10. Cupric, ferrous, ferric sulphate, and calcite	Tarnished chalcopyrite.

As indicated by the preceding experiments a solution of cupric and ferrous sulphate in contact with carbonate will precipitate carbonate of copper and hydroxide of iron, and at the same time deposit bornite on chalcopyrite. Where pyrite occurs abundantly there is more likely to be an excess of ferric sulphate over ferrous sulphate. In the absence of calcite gangue secondary bornite would not be deposited on primary chalcopyrite in the zone of oxidation where sulphuric acid and ferric sulphate are present. Unless active sulphides or gangue minerals are present ferric sulphate will not readily be reduced and cupric sulphate will migrate farther down without being impoverished. Enrichment of sulphides in this case would be expected at greater depth.

Under similar geologic conditions, the vertical extent of enriched sulphide zone, therefore, depends in part on the mineral composition of the primary ore, as has already been pointed out by Emmons.[1] If deposits carry alabandite, or pyrrhotite, or sphalerite, or tetrahedrite or other active sulphides ferric sulphate is readily reduced and furthers precipitation of secondary sulphides. In the pyrrhotite bearing sulphide deposit at Ducktown, and at Encampment district, Wyo., and several other mining districts the secondary sulphide zone is rich but less extensive in depth compared with other districts where pyrrhotite does not occur in the primary ores.

[1] Emmons, W. H., U. S. G. S. Bull. No. 529.

SERIES 4. EXPERIMENTS WITH FERRIC AND CUPRIC SULPHATE SOLUTION.

In the upper zone of copper sulphide ore deposits cupric and ferric sulphate are abundant. Secondarily deposited sooty chalcocite is supposed to have been precipitated by several reducing agents including hydrogen sulphide gas which can be generated by active sulphides when they are brought in contact with acids.

Preliminary to the experiment the acidity of important sulphates that occur in mine waters in sulphide ore deposits was tested, using methyl orange as an indicator.

Acid to Indicator.	Neutral or Alkaline to Indicator.
$Fe_2(SO_4)_3$	$FeSO_4$
$CuSO_4 \cdot 5H_2O$	$ZnSO_4$
H_2SO_4	$MnSO_4$
	$MgSO_4$
	$CaSO_4$

Pyrrhotite, sphalerite and alabandite were treated with those sulphates reacting acid to the indicator and the following results were obtained

ACTION OF ACID SOLUTION ON PYRRHOTITE, SPHALERITE, AND ALABANDITE.

Acid Solution.	Pyrrhotite.	Sphalerite.	Alabandite.
H_2SO_4	H_2S evolved.	H_2S evolved.	H_2S evolved.
$Fe_2(SO_4)_3$	H_2S evolved.	H_2S evolved.	H_2S evolved.
$CuSO_4$	No H_2S.	No H_2S.	No H_2S.

The behavior of a mixed solution of ferric and cupric sulphates was determined in the following experiments. Minerals one gram each, 80–200 mesh, were put in test tubes and 25 c.c. of tenth normal cupric sulphate and 25 c.c. of ferric sulphate, tenth normal with respect to iron, were added. The acidity and amount of reduced iron were tested at several intervals. The results are shown in the following Tables IV. and V.

It was found that pyrrhotite and sphalerite did not evolve hydrogen sulphide gas in the presence of N/10 $CuSO_4$ as has al-

TABLE IV.

RELATIVE ACTIVITY OF MINERALS IN REDUCING ACIDITY OF N/10 $CuSO_4$ AND $CuSO_4$ AND $Fe_2(SO_4)_3$, N/10 WITH RESPECT TO IRON.

Minerals in Order of Activity.	1 Day.	2 Days.	4 Days.	8 Days.	18 Days.
Calcite	1.5	0.0	0.0	0.0	0.0
Siderite	3.1	2.8	2.4	1.6	0.3
Tetrahedrite	3.3	3.2	3.0	2.6	1.9
Galena	3.3	3.2	3.1	2.7	2.2
Pyrrhotite	3.3	3.2	3.2	3.1	2.6
Arsenopyrite	3.2	2.9	2.8	2.7	2.7
(Chalcocite)	3.2	3.2	3.2	3.1	2.7
Sphalerite	3.2	3.2	3.2	3.1	2.7
Pyrite	3.2	3.2	3.2	3.1	2.9
Marcasite	3.2	3.2	3.2	3.1	3.1
Enargite	3.3	3.3	3.3	3.3	3.2
Chalcopyrite	3.3	3.3	3.3	3.3	3.3

Minerals one gram, 80–200 mesh in 25 c.c. each N/10 $CuSO_4$ and $Fe_2(SO_4)_3$, N/10 with respect to iron. 2 c.c. extract was titrated against N/10 Na_2CO_3 in each test. Figures indicate the c.c. Na_2CO_3 used in titration.

TABLE V.

RELATIVE ACTIVITY OF MINERALS IN REDUCING IRON IN SOLUTION OF N/10 $Fe_2(SO_4)_3$, N/10 WITH RESPECT TO IRON.

Minerals in Order of Activity.	1 Day.	2 Days.	4 Days.	8 Days.	18 Days.
(Siderite)	0.2	0.3	0.6	1.5	4.2
Arsenopyrite	0.2	0.4	0.7	1.5	2.6
Pyrrhotite	0.0	0.1	0.4	1.0	2.5
Tetrahedrite	0.0	0.0	0.2	0.8	2.3
(Chalcocite)	0.1	0.1	0.2	0.6	1.7
Galena	0.1	0.1	0.2	0.6	1.6
Sphalerite	0.0	0.0	0.0	0.3	1.4
Pyrite	0.0	0.0	0.0	0.2	1.2
Marcasite	0.0	0.0	0.0	0.2	1.2
Chalcopyrite	0.0	0.0	0.0	0.0	0.5
Calcite	0.0	0.0	0.0	0.0	0.0

Minerals one gram, 80–200 mesh in 25 c.c. each N/10 $CuSO_4$ and $Fe_2(SO_4)_3$, N/10 with respect to iron. 2 c.c. extract was titrated against $KMnO_4$, 1 c.c. was equivalent to 0.0016 gr. FeO, in each test. Figures indicate the c.c. $KMnO_4$ used in titration.

ready been noted by Grout.[1] Even when high temperature was employed no H_2S was generated. It was thought that a thin film of copper precipitate might have been formed around the mineral grains and prevented further action of acid, consequently

[1] Grout, F. F., ECON. GEOL., Vol. 8, p. 415.

inhibiting evolution of hydrogen sulphide gas. The following test was made:

One gram of pyrrhotite passed through a No. 20 and caught on a No. 40 mesh was treated with 25 c.c. of cupric and ferric sulphate solution and heated for five minutes. It was filtered and the mineral was washed thoroughly with hot water until the wash water showed no trace of copper. A few c.c. of fuming nitric acid was added to dissolve mineral coating which was supposed to be there. The same amount of nitric acid was added to a blank. Both solutions were filtered, and sufficient amount of ammonia was added and warmed to precipitate iron. The two filtrates were colorimetrically compared. A slight indication of an addition of copper could be detected. The retarding action by $CuSO_4$ is possibly due to the formation of thin film of secondary sulphide on primary mineral or it may be attributed to some other property of $CuSO_4$.

In connection with this experiment further study on the precipitation of sulphide was made with alabandite. Pieces of pyrite and chalcopyrite and ground alabandite were put in a test tube, and cupric and ferric sulphate solution were introduced. At the end of two days it was noted that hydrogen sulphide gas was generated and copper sulphide was precipitated, and pyrite and chalcopyrite were coated with chalcocite and bornite respectively. A trace of chalcocite coating on bornite coating was noted on the chalcopyrite.

SUMMARY AND CONCLUSIONS.

The action of sulphuric acid and metallic sulphate solutions on many metallic sulphides and other minerals results in a gradual decrease in acidity and a general tendency toward neutralization.

Ferric sulphate attacking sulphides in the presence of some oxygen did not increase acidity at any stage of the experiments.

In the reduction of acidity as well as in the reduction of ferric iron, the rate of activity of sulphide minerals varies greatly.

Acidity of descending solutions should decrease with depth, and ultimately the solutions would become neutral or alkaline.

Other factors being equal, the vertical extent of secondary sulphide zone should show a relationship to the mineral composition of the primary ores.

Either sulphuric acid or ferric sulphate or both generate hydrogen sulphide gas when brought in contact with pyrrhotite or sphalerite or alabandite, but cupric sulphate does not generate hydrogen sulphide.

It was found that manganese sulphide, probably alabandite, is present in small amounts in many specimens of galena and marcasite from widely separated regions. Of many specimens of galena in the laboratory collection at the University of Minnesota not one was found to be free from manganese sulphide. Since alabandite is nearly fifteen times as active as pyrrhotite, according to Grout, it appears certain that the hydrogen sulphide evolved from these sulphides was due almost wholly to the manganese sulphide.

In a mixed solution of cupric and ferrous sulphate in the presence of calcite the deposition of bornite on chalcopyrite began only when the solution had become nearly neutral.

In the presence of cupric sulphate, very weak acids acting on pyrrhotite and sphalerite do not generate hydrogen sulphide gas.

The writer is much indebted to Dr. W. H. Emmons, under whose personal direction this problem has been worked out, and to Professor F. F. Grout, who outlined the experiments and who has kindly given valuable suggestions and assistance throughout the investigation.

SPRING DEPOSITS AT SULPHUR SPRINGS, ARK.[1]

C. E. SIEBENTHAL, WITH MICROSCOPIC EXAMINATION BY H. E. MERWIN.

LOCATION.

Sulphur Springs, Arkansas, is a small resort about 9 miles a little south of east of the northwest corner of the State. A number of springs issue in a small park in the valley of Butler Creek, which flows northwestward about five miles and empties into Elk or Cowskin River. The elevation of the springs is about 920 feet and the creek valley is bordered by hills 200 to 250 feet in height.

GEOLOGY.

The geology of the region has been described in the Fayetteville geologic folio, by Adams and Ulrich. The surface rocks over the plain in which the valley of Butler Creek is trenched belong to the Boone limestone, of Mississippian (lower Carboniferous) age. These rocks accordingly form the upper portions of the hills in the vicinity of Sulphur Springs where they are exposed for a thickness of 150 to 200 feet, inclusive of the St. Joe limestone member, which forms the basal portion of the Boone and has a thickness of 25 to 30 feet. Beneath this limestone lie Devonian rocks, comprising the Chattanooga shale, consisting of 40 to 60 feet of black shale with the Sylamore sandstone member at base. The sandstone lies on an irregular eroded surface of Ordovician rocks and in places has a thickness of 10 feet. About a mile north of the springs the Ordovician rocks show a thickness of 50 feet of cherts and dolomitic limestones. They comprise the oldest formation exposed in the region.

[1] Published with the permission of the Director of the United States Geological Survey.

RELATION OF THE SPRINGS TO THE DEEP WELLS AND TO THE ORIGIN OF THE JOPLIN ORE DEPOSITS.

The horizon of the springs is about 25 feet below the top of the Ordovician and corresponds closely to that of the so-called "radium water" of the artesian wells of northeastern Oklahoma, which generally derive their flow from sandstones or limestones not far below the Chattanooga shale. The deep wells of southeastern Kansas likewise draw their supply from rocks below the horizon of the Chattanooga shale. Bain,[1] Van Hise,[1] Tangier Smith,[2] and the writer[3] maintain that the zinc and lead ore-bodies of the Joplin region were deposited by the water of an artesian circulation which developed upon the sloping sides of the Ozark uplift. They believe that this water, in passing outward and downward through the Ordovician and Cambrian rocks, dissolved and collected the metals and, on ascending to the surface, deposited them at the inner edge of the surrounding Pennsylvanian shale, which acted as an impervious cover, and so limited the artesian circulation.

The writer has elsewhere suggested that the waters of the deep wells in the Pennsylvanian area in southeastern Kansas and northeastern Oklahoma, having been impounded for ages beneath the overlying shale, more nearly represent the water of the original circulation—that is, the ore-bearing solution— than do the deep well waters of the district itself, since these well waters, having circulated freely, must have changed more or less in character. The waters of the deep wells beneath the Pennsylvanian are relatively high in alkali chloride salinity and contain free CO_2 and free H_2S. It is believed by the writer that surface waters containing free CO_2, on entering the artesian circulation upon the higher part of the uplift, dissolved the disseminated sulphides

[1] Bain, H. F., Van Hise, C. R., and Adams, G. I., "Preliminary Report on the Lead and Zinc Deposits of the Ozark Region," U. S. Geol. Survey, Twenty-second Ann. Rept., pt. 2, pp. 49–52, 207–215, 1901.

[2] Smith, W. S. Tangier, and Siebenthal, C. E., U. S. Geol. Survey Atlas U. S., Joplin folio (No. 148), p. 18, 1907.

[3] Siebenthal, C. E., "The Origin of the Zinc and Lead Deposits of the Joplin Region," U. S. Geol. Survey Bull. 606 (in press).

of the metals as bicarbonates and liberated H_2S, and that the solution and the dissolved gas were carried along in the artesian circulation. As the water approached the surface CO_2 escaped and the metals were re-precipitated by the H_2S yet present. For the data upon which this conclusion is based and for other reactions that may have taken part in the solution and transportation of the metals, the reader is referred to the writer's bulletin on the ores, now in press. The present paper will discuss only the composition of the waters of the springs and their deposits, in the light of the foregoing considerations.

CHARACTER OF THE WATERS.

Only two trustworthy analyses of the waters of these springs are known. The water of the White Sulphur Spring was recently analyzed by Prof. W. George Waring of Webb City, Mo., and the water of "Sulphur Spring"[1] was analyzed by Dr. A. E. Menke, of the Arkansas State University. As there are two sulphur springs, one called the "White Sulphur Spring" and the other the "Black Sulphur Spring," it is not known from which spring the water analyzed by Menke was obtained, but the difference between this analysis and that made by Waring indicates that Menke's analysis probably refers to the "Black Sulphur Spring." Both springs contain a small quantity of free H_2S gas, which at the springs is plainly evident to the smell and to the taste, but which has entirely disappeared by the time the sample reaches the laboratory. Small samples of the water of each spring, tested with rosolic acid and other indicators by Dr. E. T. Allen, of the Geophysical Laboratory of Carnegie Institution, show that the water is neutral or very faintly alkaline. For the purpose of comparing these waters with some of the nearly related deep well waters and with mine waters at Miami, the convenient method described by Dr. Chase Palmer[2] has been adopted and the result

[1] Branner, J. C., "The Mineral Waters of Arkansas," Ark. Geol. Survey, Ann. Rept. 1891, Vol. 1, p. 96, 1892.

[2] Palmer, Chase, "The Geochemical Interpretation of Water Analyses," U. S. Geol. Survey Bull. 479, 1911.

is set forth in the accompanying table. Space does not permit a repetition here of the definition and explanation of Dr. Palmer's terms, and the reader is referred to Dr. Palmer's paper.

The water of the White Sulphur Spring corresponds very closely indeed to the water of deep well No. 2 at the waterworks at Clinton, Mo., and to the water from the Chapman & Lennan mine at Miami, Okla., when first sampled. The Clinton well penetrates Pennsylvanian to Cambrian rocks, drawing its water supply from the latter. The Chapman & Lennan mine lies below Pennsylvanian shale, which prevents the ingress of surface water. The mine water is highly charged with H_2S and agrees so closely with deep well waters in its high content of chlorides and alkali metals that it seems surely of deep-seated origin, and the writer believes that it represents fairly the circulating artesian water from which the ores were deposited. If so, it came from the Cambrian and Ordovician rocks, the same great series which furnishes the water of the Clinton well and the Sulphur Springs. Coming from the same horizon and having the same general properties as the well and mine water, therefore, the water of the White Sulphur Springs seems to the writer likewise to represent the circulating artesian water from which the ores were deposited.

The water of the Black Sulphur Spring, if we may so refer the analysis of water from the "Sulphur Spring" by Dr. Menke, approaches closely the water from the Chapman and Lennan mine at the time of the second analysis, made three months after the first analysis, when the mine opening was larger and when the water had begun to show the influence of mixture with the drainage from neighboring mines. This influence is shown in the decrease of its content of chlorides and alkali metals and in the increase of its content of carbonates and alkaline-earth metals. Among the deep well waters, that from the well at the ice-plant in Miami, Okla., compares closely with the Sulphur Spring water, but the well water has a higher content of the alkali metals and a considerably higher chloride salinity. The well water thus seems to be intermediate in character between the White Sulphur Spring well and the earlier mine water, on the one hand, and

COMPARISON OF THE WATER OF SULPHUR SPRINGS WITH DEEP WELL AND MINE WATERS.

Source of Water	Clinton, Mo., Well	Chapman & Lehman Mine	White Sulphur Spring	Miami, Okla., Well	Chapman & Lehman Mine	"Sulphur Spring"
Analyst	A. E. Woodward	W. George Waring	W. George Waring	John F. Wixford	W. George Waring	A. E. Menke
Date of Analysis	1892	Sept. 12, 1912	1914	1907	Dec. 23, 1912	1891
Properties of reaction	Percentage	Percentage	Percentage	Percentage	Percentage	Percentage
Primary salinity	58.6	58.4	55.2	50.2	44.4	43.2
Secondary salinity	8.4	7.0	10.4	9.6	.....	.....
Primary alkalinity	.....	.....	.....	.....	.....	.....
Secondary alkalinity	33.0	34.6	34.4	40.2	55.6	56.8
Total	100.0	100.0	100.0	100.0	100.0	100.0
Chloride salinity	55.8	58.6	60.2	56.6	44.4	38
Sulphate salinity	11.2	6.8	5.4	3.2	.....	4.6

Reacting values of constituents	Percentage	Parts per million	Percentage	Parts per million	Percentage	Parts per million	Percentage	Parts per million	Percentage	Parts per million	Percentage	Parts per million
Sodium (Na)	26.1	8.872	29.2	3.841	19.2	2.675	25.1	2.854	22.2	4.052	21.6	3.053
Potassium (K)	3.2	1.085	tr	tr	8.4	1.178	.....	.....	.....	.....	.....	.....
Alkalies	29.3		.....		27.6		25.1		22.2		21.6	
Calcium (Ca)	11.8	4.012	13.6	1.797	12.8	1.791	14.1	1.605	20.2	3.683	15.7	2.221
Magnesium (Mg)	8.9	3.001	7.2	.9420	9.6	1.342	10.8	1.225	7.6	1.397	12.7	1.801
Earths	20.7		20.8		22.4		24.9		27.8			
Reacting values bases		16.97		6.580		6.986		5.684		9.132	28.4	7.075
Sulphate (SO_4)	5.6	1.906	3.4	.4447	2.7	.3773	1.6	.1874	tr	.....	2.3	.3208
Chloride (Cl)	27.9	9.478	29.3	3.863	30.1	4.205	28.3	3.215	22.2	4.052	19.3	2.732
Strong acids	33.5		32.7		32.8		29.9		22.2		21.6	
Bicarbonate (HCO_3)	16.5	5.585	17.3	2.272	17.2	2.404	20.1	2.282	27.8	5.080	28.4	4.022
Weak acids	16.5		17.3				20.1		27.8		28.4	
Reacting values acids		16.97		6.580	17.2	6.896		5.684		9.132		7.075
Total Reacting values solids		33.94		13.16		13.97		11.374		18.26		14.15

Source of Water Analyst Date of Analysis	Clinton, Mo., Well A. E. Woodward 1892	Chapman & Lehman Mine W. George Waring Sept. 12, 1912	White Sulphur Spring W. George Waring 1914	Miami, Okla., Well John F. Wixford 1907	Chapman & Lehman Mine W. George Waring Dec. 23, 1912	"Sulphur Spring" A. E. Menke 1891
Base Analysis	Parts per million	Parts per million	Parts per million	Parts per million	Parts per million	Parts per million
Total weight of reacting solids	1132	433	474	375	637	494
Colloids:						
Iron (Fe_2O_3)	.....	1	1	.....	.....	3
Alumina (Al_2O_3)	.....	.....	3	.....	.....	4
Silica (SiO_2)	4	9	8	9	11	12
Total solids	1136	443	486	384	648	513
Free gases:						
Carbon dioxide (CO_2)	?	22	6	3	22	?
Hydrogen sulphide (H_2S)	1	2	present	present	strong	present

the "Sulphur Spring" and the more recent mine water, on the other.

Enough has been said to show that the waters of the springs at Sulphur Springs, Ark., are essentially similar in source and quality to the deep well waters in the region to the northwest, and to the solutions which deposited the ores. This resemblance is more strikingly shown by a study of the extensive series of analyses of waters from deep wells and other sources which the writer has compiled in the bulletin now in press.

THE SEDIMENTS FROM THE SPRINGS.

Chemists analyzing the deep well waters of the Joplin region have found that the sediment which at length settles to the bottom of the containers of waters carrying H_2S, includes lead, zinc, copper, and iron, if these metals were originally in the water. With this fact in mind, the writer collected sediment from the White Sulphur Spring and from the Black Sulphur Spring. Each spring is walled up and cemented to form a basin about 2 feet in diameter and 5 or 6 feet in depth. The top of the basins are closed with wooden covers and surmounted by small hand pumps. The sediment consists of metallic sulphides, together with sand, gravel, bits of cement, and more or less organic matter. The samples were submitted to Professor Waring for partial analysis, with the following results:

ANALYSES OF SEDIMENTS FROM SPRINGS AT SULPHUR SPRINGS, ARK.

W. George Waring, analyst.

Expressed in percentages of the total dried residues.

	White Sulphur Spring.	Black Sulphur Spring.
Zinc	0.388	0.022
Lead	0.040	0.009
Copper	0.005	0.004
Iron	2.100	2.940
Sulphur	1.450	2.820
Lime	19.810	1.300
Magnesia	1.530	0.100
Silica and insoluble silicates	49.930	62.820

Megascopic examination of the sediments showed the presence of a considerable quantity of crystallized pyrite in each. In the hope that the microscope might reveal some crystals of sphalerite or galena, the sediments were submitted for closer examination to Dr. H. E. Merwin, of the geophysical laboratory of Carnegie Institution. The results of this examination, though disappointing in not yielding crystallized sphalerite or galena, are nevertheless valuable and interesting and are given herewith.

MICROSCOPIC EXAMINATION OF SEDIMENT FROM THE SULPHUR SPRINGS.

Black Sulphur Spring.—The noteworthy constituents are quartz grains and quartz crystals, pyrite, and carbonate concretions.

Many of the irregular quartz grains and those which still retain crystal outlines have been so much corroded that their surfaces are spongy.

The calcareous concretions are not numerous and are small—about .5 mm. in diameter. They have radial structure, but irregular surfaces. The refractive index of the crushed fragments is considerably higher than of pure calcite, but the concretions effervesce freely in cold dilute acid and the resulting solution reacts for iron, showing that the concretions are probably not dolomitic. The maximum refractive index, 1.69–1.71, is too high for aragonite.

The pyrite occurs in nodular aggregates, the largest about 3 mm. in diameter, and in single crystals up to .4 mm. in diameter. The cube and octahedron are the only forms recognized. The cube faces show no striations and are much less bright than the octahedron faces. By growing into the spongy surfaces of quartz grains the pyrite becomes firmly attached, and cements the grains into groups.

Many sharp-angled, bright-faced quartz crystals about .5 mm. in diameter were observed, attached to etched quartz grains in such a way as to indicate that deposition of quartz takes place in parts of the spring, probably at a distance from the source of supply.

White Sulphur Spring.—Pyrite and calcite are the only minerals which appear to be depositing in this spring. The pyrite is in nodules and single crystals, as in the other spring.

Distinct calcite crystals, .2 mm. long, were seen on a piece of iron wire taken from the spring. Smaller crystals form an oozy deposit, and other small crystals are aggregated into heavy grains. These crystals all have the optical properties of nearly pure calcite.

The quartz grains are etched and pitted but to a very much less degree than those in the Black Sulphur spring. Many of these grains are double pyramids with angles only slightly rounded. Their origin is not known.

DISCUSSION.

Dr. E. T. Allen[1] and his associates at the geophysical laboratory of the Carnegie Institution obtained crystalline marcasite at room temperatures and crystalline pyrite at 70° C. Dr. Allen regards the discovery of pyrite forming at Sulphur Springs as extending the range of the observations relating to pyrite to the same point as those relating to the formation of marcasite. Pyrite is here forming from waters in which calcite is depositing, and which are, therefore, presumably neutral or approximate the neutrality of calcium bicarbonate solutions. Tests made by Allen confirm this conclusion. The occurrence of marcasite with calcite in such association as to show their contemporaneous deposition is so common that Allen[1] was forced to conclude that marcasite may be deposited at low temperatures from solutions no more acid than calcium bicarbonate solution. The occurrence in these springs of calcite with pyrite but no marcasite suggests that in solutions containing calcium bicarbonate a very slight veering from neutrality will determine whether marcasite or pyrite shall be deposited.

[1] Allen, E. T., Crenshaw, J. L., and Johnson, J., "The Mineral Sulphides of Iron, with Crystallographic Study by Esper S. Larsen," *Am. Jour. Sci.*, Vol. 33, pp. 169–236, 1912; Allen, E. T., and Crenshaw, J. L., "The Sulphides of Zinc, Cadmium, and Mercury; their Crystalline Forms and Genetic Conditions. Microscopic study by H. E. Merwin," *Am. Jour. Sci.*, Vol. 34, pp. 341–396, 1912.

[2] *Op. cit.*, p. 382.

The foregoing analyses of the waters of White Sulphur Spring and of Black Sulphur Spring and their sediments show that they have a high content of chlorides and alkali metals similar to that of the deep well waters and that like many of those waters, upon standing they deposit a dark sediment which contains the metals as sulphides. The sediments differ from most of the sediments deposited by deep well waters, however, in containing crystallized sulphide of iron, calcite, and quartz. It was to be expected that the sediments might show dolomite as well as calcite, for the waters contain relatively large proportions of magnesium, but the microscope revealed no trace of crystallized dolomite and the analyses of the sediments show that the magnesium is deposited in relatively small quantities. Nevertheless, it appears to the writer that these waters, similar in quality to the deep waters, and to the Miami mine waters and presumably to the ore solutions, depositing, as they do, calcite, quartz, metallic sulphides, and crystallized pyrite, were undoubtedly capable not only of depositing the ores of the Joplin region but also the gangue minerals and rocks, calcite, secondary limestone, dolomite, and jasperoid.

DISCUSSION

This department has been established by the editors in order to afford to those interested in questions relating to economic geology an opportunity for informal discussion. Contributions are cordially invited either in the form of discussion of more formal papers appearing in earlier numbers or bearing upon matters not previously treated. Letters should be directed to the Editor, Sheffield Scientific School of Yale University, New Haven, Conn. The full name of the author should be attached to all communications.

THE KYNUNA WELLS—A TEST CASE OF ROCK PRESSURE.

The overflow of water from deep wells has been attributed to two chief causes: (1) the pressure of the water in those parts of a continuous sheet which are higher than the outlet and (2) various local agencies, such as gas pressure and rock pressure, which produce the "peloconic" wells of Daubrée. One of the best-known varieties of flowing wells due to water pressure was long known as artesian, but that term has become indefinite since it has been applied popularly to any deep well, and is used industrially for all bored wells in distinction from dug wells. Hence the original meaning of artesian has largely fallen into disuse. The Geological Survey of the United States however retains the word "to designate the hydrostatic principle by which confined waters tend to rise in virtue of the pressure of the overlying water column, whether or not this pressure is sufficient to lift the water to the surface and produce a flow."[1]

This definition is however unsatisfactory in practice, for in many a well long observations may be required to explain the rise of its water.

An instructive illustration of wells which are called artesian but in which the flow is due to rock pressure, perhaps aided by gas pressure, is afforded by those of Kynuna in western Queens-

[1] M. L. Fuller, "Summary of the Controlling Factors of Artesian Flows," U. S. Geol. Surv., Bull. 319, 1908, p. 8.

land. Kynuna (Fig. 170) is situated on the western plains of Queensland around 21⅔° S. and 142° E.; it is seventy miles south of Eddington on the Cloncurry railway, and is in the Diamantina basin, a little south of the watershed between that river and the Flinders River, which discharges to the Gulf of Carpentaria.

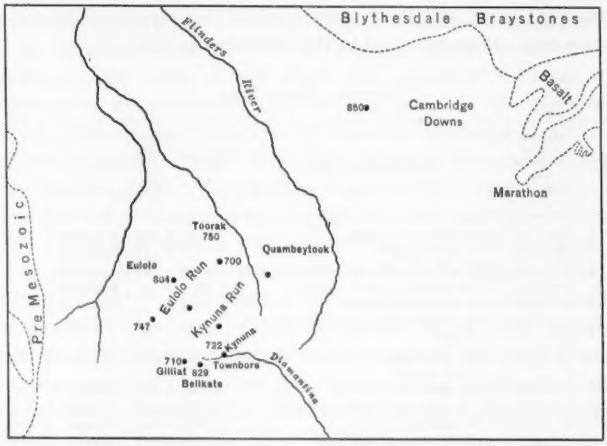


FIG. 170. Sketch map of some wells around Kynuna. The heights give total head of the water in feet above sea level.

The surrounding country consists mainly of open plains usually between 650 and 850 feet above sea level, and composed of shales belonging to the Rolling Downs Formation; 110 miles to the north-east is the margin of an area of sandstone—the Blythesdale Braystone. Sandstone is also found under the Rolling Downs Formation in the wells around Kynuna; and the conclusion was naturally adopted that percolation through the Blythesdale Braystone feeds the wells of the western plains.

The well at Kynuna Town is 2,221 feet deep and obtained its water from twenty-two different beds, including sand, sandstones, sand-rock, and gravel. These beds are in thin layers and some are only four feet thick; and they are interstratified in thicker

shales. A detailed section of the bore has been published by the Water Supply Department of Queensland (Sect. No. 214). Its interesting and careful record shows that the water from the successive beds rose to steadily increasing heights, until at length the water from below the depth of about 2,000 feet overflowed at the surface. The different water bearing beds, their depths below sea level, and the height to which the successive layers of water rose are enumerated in the following table:

KYNUNA TOWN BORE.

Flow No.	Depth Above or Below Sea Level, Ft.	Water-bearing Bed.	Water Rises, Ft.	Rise to Above or Below Sea Level, Ft.	Water.	
1	+ 385	9 ft. of sandy shale	40	+425	Brackish	
2	+ 235	8 ft. greensand	80	+315	Brackish	
3	− 145	Top of 72 ft. of sandstone and clay	120	− 25	Brackish	
4	− 415	12 ft. sandrock and gravel	360	− 55	Brackish	
5	− 513	5 ft. gray sandstone	560	+ 47	Brackish	
6	− 624	4 ft. sandy shale with beds of sandstone	959	+335	Fresh	
7	− 703	12 ft. gray and white sandstone and fossil wood	1,232	+529	Fresh	
8	− 775	14 ft. gray sandstone	1,350	+575	Fresh	
9	− 917	12 ft. gray sandstone and silt	1,510	+593	Fresh	
10	− 979	6 ft. clayey sand	1,586	+607	Fresh	
11	−1,037	11 ft. sandstone and silt	1,660	+623	Fresh	
12	−1,083	15 ft. sandstone, silt and mud	1,720	+637	Fresh	
13	−1,202	26 ft. blue and gray sandstone	1,851	+649	Fresh	
14	−1,278	4 ft. clay and sandstone with pipe clay				125° F.
15	−1,282					125° F.
16	−1,288	101 ft. fine sandstone				137° F.
17	−1,320					145° F.
18	−1,360			+722	Fresh	146° F.
19	−1,390	5 ft. coarse sandstone				147° F.
20	−1,423	8 ft. sandstone and pipe clay				147° F.
21	−1,431	30 ft. sandstone with carbonized wood				149° F.
22	−1,524	15 ft. sandstone				150° F.

Many other bores have been put down in this district; and they show the distribution of the rocks and of the water along a series of lines parallel to the edge of the supposed intake bed, which trends from west-northwest to east-southeast. Thus one series of bores shows the conditions along a line about thirty miles from

the edge of the Blythesdale Braystone across the Cambridge Downs to Marathon; a second series passes from Toorak to Quambeytook; a third line passes from the northeast of the Eulolo Run through the Kyuna Town bore; and the fourth line crosses the southwestern parts of the Eulolo and Kynuna Runs. If the water from these bores were derived from the Blythesdale Braystone and were overflowing around Kynuna in consequence of the hydrostatic pressure of the water at higher levels to the northeast, the bores should show the existence of a continuous series of permeable beds extending from the supposed intake to the bores. There should moreover be a steady fall from the intake southwestward; and all the wells of this group should vary together, as they would all be dependent on a common source of water and pressure. These requirements however are not fulfilled. The well sections published by the Water Supply Department of Queensland do not indicate that the separate water bearing beds are continuous under the area. It is indeed doubtful whether the main water bearing bed at Kynuna is the Blythesdale Braystone. That formation is described as a thick continuous sandstone; and this description would correspond with the sandstones found at the bottom of the well on the Cambridge Downs, about twenty-five miles from the Blythesdale Braystone outcrop; the long succession of thin bedded shales, marls, limestones, clays and sandstones in the upper part of Kynuna Town bore no doubt belong to the Rolling Downs Formation; but the presence of carbonized wood and pipe-clay in the underlying beds and the presence of a seven-foot seam of coal in well No. 5 at Kynuna suggests that the wells had passed into the Jurassic Coal Measures. Still further to the southwest, in bores at Gilliat and Bellkate on Kynuna Station, the sections report one thick sheet of shale or blue shale resting upon a massive sandstone, 210 feet thick at Gilliat and 317 feet thick at Bellkate. Each of these sandstones is descibed as resting on quartzite; and this quartzite may belong to the lower Palaeozoic or Palaeozoic rocks, which outcrop less than fifty miles to the west. The apparent differences in the well sections may be partly due to the other wells having been recorded in less detail than the Kynuna Town bore;

but the correlation of the sandstones beneath Kynuna with the Blythesdale Braystone is at least uncertain.

Comparison of the well records indicates that the rocks in the district are very variable, and it is unlikely that the separate layers of sandstone passed through in the Kynuna Town bore should extend for over one hundred miles northeastward to the outcrop of the Blythesdale Braystone. Most of them are probably thin lenses of sandstone, which are included in the predominant sheet of shale, and are isolated from the surface waters.

It is therefore improbable that the water from these water bearing pockets should rise up the wells in consequence of hydrostatic pressure from water in the Blythesdale Braystone. Moreover it is equally improbable that each layer should act as an independent pipe, and transmit pressure independently from recent surface water. The uppermost layers in the well would on the hydrostatic theory derive their supplies from levels but little above their own heights. It would only be the deeper layers that would

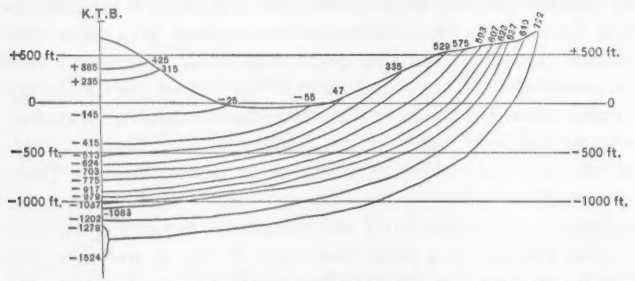


FIG. 171. Diagram of the Kynuna well showing the heights to which the water rises from the successive water bearing beds. The surface is the hypothetical surface required on the hydrostatic theory. The actual surface is above 520 feet.

obtain their supplies from beds higher than the mouth of the well. The surface levels required on the hydrostatic theory may be diagrammatically illustrated by Fig. 171 (in which the friction factor has been ignored). There is however no surface depression by which the successive water beds could be fed from such levels.

It may be suggested that only the deeper layers may obtain their water from the Blythesdale Braystone and depend for their rise on hydrostatic pressure through that formation; but the increase in the ascent of these waters is so steady that there appears no reason for the introduction of different factors to explain the ascent of the lower and upper waters.

Another difficulty in the hydrostatic theory is that the variation in the height of the water at the different wells is inconsistent with its requirements. Thus Fig. 172 shows the hydrostatic head attained by the water in some wells in this district. On the higher ground of the Cambridge Downs the water rises to heights in places of 850 feet. In the next series of wells to the west-southwest the water in the well at Toorak rose to the height of 785 feet and to about 750 feet at Kynuna Run. In the next series to the west-southwest, the level rose at Eulolo to to 804 and 768 feet, and at Kynuna Town bore to about 722 feet. Then in the next series to the west-southwest the level of the four western wells at Eulolo and Kynuna Station are 747, 709, 805 and 819 feet respectively. Hence the hydrostatic head rises instead of falling to this last line.

Further difficulties are the short life of these wells and the fact that they cease to flow independently of one another. The average length of the life of a well in the Kynuna district has been estimated at seven to eight years. Numerous cases of these wells ceasing to flow are referred to in my paper of 1911[1] and the Queensland Water Supply Department has supplied later evidence that this process still continues.[2] Now if these wells were all drawing upon a continuous stream of underground water flowing south-westerly, it is improbable that they should vary so irregularly. It would of course be possible that some wells might fail owing to their channels becoming choked by silt; but this explanation is inadequate.

Again the temperature of the Kynuna waters is abnormally high for their depth. If the water is of modern meteoric origin

[1] "The Flowing Wells of Australia," *Geographical Journal,* July and August, 1911, p. 54.

[2] Map of Artesian Borings and Perennial Springs in Queensland, 1911.

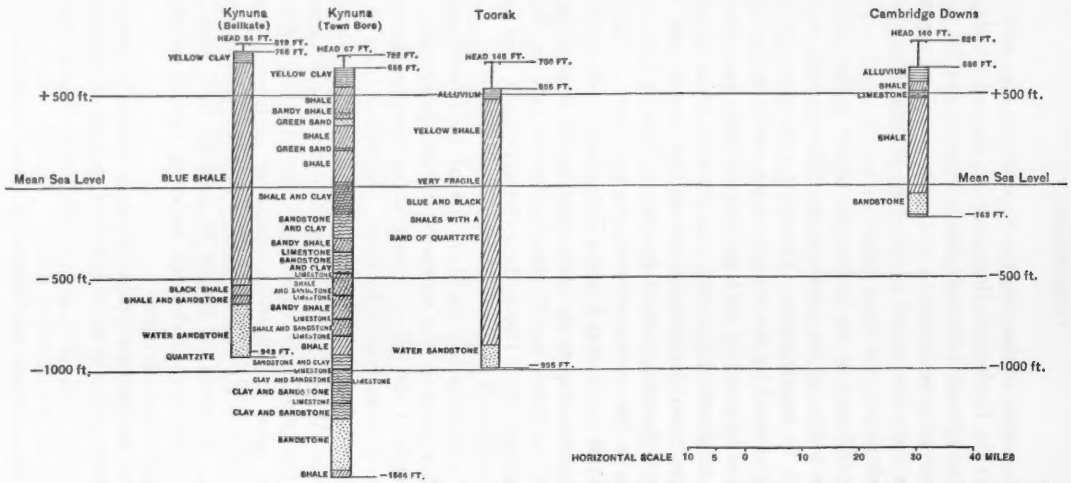


FIG. 172. Section through a series of wells on a line southwest from Cambridge Downs, showing rise in the head of water going away from the supposed intake beds.

it indicates the abnormally rapid temperature gradient of about 1° F. for twenty-eight feet of descent; but its high temperature is easily understood if the well water is discharged from an ancient store and contains some plutonic water.

The behavior and flow of this group of wells may be attributed to the effects of rock pressure. The Kynuna Town well is fed by twenty-two water charged sheets, which are under heavy pressure from the overlying beds; and the deeper the water-bearing bed, the greater the pressure upon it from the overlying rocks and therefore the greater the height to which the water from it is forced, when this sealed bed is penetrated by a bore. The coincidence that throughout these twenty-two layers the height to which the water ascends steadily increases with the depth shows that the ascent and depth are closely connected. As the Kynuna wells drain only isolated beds of sand they discharge only water of cisternage; and it is only natural to find that their outflow diminishes and that the rate of decrease varies with the local conditions of each well.

J. W. GREGORY.

REVIEWS

The Deposits of the Useful Minerals and Rocks; their Origin, Form and Content. By F. BEYSCHLAG, J. H. L. VOGT, AND P. KRUSCH. Translated by S. J. TRUSCOTT. In three volumes. Vol. I., Ore-deposits in general; Magmatic segregations; Contact deposits; Tin lodes; Quicksilver lodes. Octavo, 514 pages with 291 illustrations. Macmillan, London, 1914. (The Macmillan Co., New York. Price $5.00.)

Logically the reviewer of a translation may be expected to confine himself to the work of the translator—a rather barren task. Inasmuch, however, as the appearance of the above volume in English makes it available for the first time to a large number of readers, it will probably be more interesting and profitable to consider the substance of the book as well as its present rendition and form. The reviewer should explain, however, that the German text was not at hand where this review was written and consequently it has not been possible in some cases to determine whether responsibility for the form of statement rests with the authors or with the translator.

The volume is divided into sections corresponding to chapters although these are not numbered in the usual way.

The *Introduction* calls attention to the modern endeavor to determine the geologic relations and genesis of ore deposits rather than to study merely their form and content. In other words, the study of ore deposits is a branch of geology and examples are cited of the successful practical application of geologic knowledge and methods to mining problems.

Under *Classification, Form,* and *Graphic Representation of Ore Deposits,* the deposits are divided as follows:

A. Syngenetic deposits:
- (1) Magmatic segregations.
- (2) Sedimentary ore-beds.
- (3) Gravel deposits.

B. Epigenetic deposits:
- (1) Contact-metamorphic deposits.
- (2) Cavity-fillings.
- (3) Metasomatic deposits.
- (4) Impregnations.

Most American students will probably not immediately see any obvious

distinction between classes (1), (3) and (4) of the epigenetic deposits, nor will they recognize the force of the illustration given in the statement "a number of deposits of widely different genesis may often have the same form, as for instance contact-metamorphic and metasomatic occurrences." Here, and in most places in the book, the term *metasomatic* is restricted to deposits formed by the replacement of soluble rocks without accompanying contact phenomena. This, however, is not justifiable. Metasomatism is not exclusively a low-temperature process but on the contrary is highly characteristic of contact action where limestones are involved. In one place (p. 372) the authors virtually admit this and ignore their previous distinction by referring to the iron ores of Elba as "formed by molecular replacement of the limestone by contact-metasomatism."

The statement (p. 16) that the difference between gravel deposits and ore beds consists entirely in the fact that ore beds are consolidated and are covered by other beds whereas gravel deposits are chiefly loose surficial deposits is unsatisfactory as a basis for classification.

In this chapter also are described the effects of folding and faulting on the various deposits. The scarcely justifiable assumption is made that normal faulting implies real downward movement of the hanging wall. Objection may also be taken to the definition of composite lode as one in which fragments of the hanging wall fell into the fissure before ore deposition took place.

The chapter on Manner and Cause of Fracture is brief and rather inadequate.

The following chapter on the Mineral Content of Ore-deposits deals with a greater variety of topics than would be expected from its title. It divides the materials of ore-deposits into (1) ore, (2) gangue, and (3) rock inclusions and describes not only the mineralogy of (1) and (2) but their structures also. The definition of ore is needlessly long although fairly satisfactory in concept. The mineralogy of ores is well treated but exception might be taken to a number of statements, such as "the gold tellurides are generally quite dull in appearance," "cupriferous pyrite," and the characterization of bornite as a typically secondary mineral. Wurtzite is nowhere mentioned. Under zinc ores, calamine is listed as zinc carbonate while smithsonite is omitted. On subsequent pages when calamine and smithsonite are mentioned it is generally impossible to tell whether the carbonate or silicate is referred to, although on page 137 smithsonite is apparently used for the carbonate. This confusion is perhaps due to the unfortunate English practice of calling the carbonate *calamine* and the silicate *smithsonite* and may be laid at the translator's door. A similar confusion arises from the common use in this book of *drusy* to express a cavernous or vuggy structure. This

usage has abundant exemplification but the word *druse* signifies a brush and properly refers to the clusters of implanted crystals that may project from the walls of a vug. With this understanding the expression "a drusy vug" has a definite meaning which is lost when *druse* and *vug*. *drusy* and *vuggy* are loosely used as synonymous terms. It is assumed that because a mineral fills cracks in an older mineral it must have been deposited in the "cementation" or "secondary" zone. This of course is not necessarily true.

The following section is entitled Mineral Formation and deals especially with (1) Crystallization from molten silicate solutions, (2) mineral formation by sublimation, (3) mineral formation resulting from the decomposition of gases and vapors by heat, (5) mineral formation by the action of gases or vapors upon solid bodies, and (6) crystallization or precipitation from aqueous solution. The discussion, although necessarily brief, is good. Attention is called to the precipitative action of various sulfides on ore-bearing solutions. As the German original was published in 1909 the treatment is not in all respects up to date.

A brief chapter on the Relative Distribution of the Elements is followed by one on the Natural Association of the Elements, with Especial Reference to the Metals, in which, among other interesting facts, is brought out the frequent presence of manganese in siderite.

The important subject The Origin of Ore Deposits is rather too briefly treated and contains very little new. The statement is made, p. 179, that contact deposits do not extend into the eruptive itself, which of course is not strictly true. The distinction made between "old" and "young" veins is not clearly drawn.

The chapter on The Absolute and the Relative Amounts of the Metals in Useful Ore-deposits is chiefly a statistical digest and comparison of the principal known deposits of each metal. No account is taken of the great bodies of disseminated copper ores developed during the past few years in this country and Chili and the statement that from one third to one half of the world's copper comes from chalcopyrite is probably not true. The assertion that in gold lodes a depth of 1,000 feet is "critical," the context implying that the tenor of the ore is likely to fall off at that depth, is certainly too sweeping.

A chapter is devoted to Primary and Secondary Depth Zones, is brief and is now scarcely abreast of modern knowledge. It is followed by one on the Indications of Ore Deposits at the Surface, in which attention is called to the value, in certain localities, of particular plants as indicators of metals.

The reader is likely to be surprised on turning to the next chapter to find it headed The Scientific Classification of Ore-deposits, inasmuch as classification was dealt with in the second chapter. The various pre-

viously proposed classifications are reviewed and the authors decide upon one which differs considerably from that given in the second chapter. Its major heads are as follows:

I. Magmatic segregations.
II. Contact deposits.
III. Cavity-fillings and metasomatic deposits.
IV. Ore-beds.

The division into epigenetic and syngenetic deposits is abandoned and the deposits under each of the above heads are subdivided, partly on the basis of the contained metal or metals. The order in which the deposits are treated in the descriptive part of the work is that of the above classification. The present volume closes with the description of the so-called Quicksilver Lodes, the third subdivision under Class III., the first being Tin Lodes and the second Apatite Lodes. The Rio Tinto pyritic deposits, the Sudbury nickel deposits, and the bornite-chalcopyrite deposits of northwest Cape Colony are classed with the magmatic segregations.

The work as a whole is not characterized by unusual originality. It constitutes, however, a very fair summary of what was known about ore deposits when it was written, its value in this respect being increased by the references given under the more important headings. Rather less attention perhaps is paid to American work on ore deposits than is deserved and the references to American literature were not quite up to date even when the original German edition was published.

The translator has done his work well. He evidently realized that translation calls for something more than the substitution of English for German words without changing the structure of the sentences. The frequent occurrence of the barbarism "payable" ore, "payable" deposits, is one of the most noticeable blemishes. *Zone* is rather loosely used not only for a range of depth but for the actual material that may lie between the upper and lower limits of that range. The subject index is not wholly reliable. For example it cites only pages 137 and 163 for smithsonite, whereas important references to the mineral are found also on pages 145, 214 and 218. There is also a useful geographical index.

The typography and illustrations, as is usually the case in Macmillan books, are excellent and half tones are used successfully without recourse to highly glazed and therefore highly objectionable paper.

F. L. Ransome.

SCIENTIFIC NOTES AND NEWS[1]

Samuel Franklin Emmons Memorial Fellowship.

The friends of the late Dr. Samuel Franklin Emmons have established a fund whose income may be used in support of a fellowship to promote investigations in the branches of geology which were cultivated by him, more especially on the economic side. The funds have been placed in charge of the Trustees of Columbia University, but the choice of the fellow and the expenditure of the income are entrusted to a committee consisting of Professors James F. Kemp, John D. Irving and Waldemar Lindgren. The committeee announces that it will be prepared to award in March, 1915, a fellowship of $1,000 for the year July 1, 1915, to June 30, 1916, inclusive. Applications must be made on blanks which will be furnished by the Secretary of Columbia University, New York, N. Y., and which when filled and accompanied by testimonials and complete statements of the applicant's qualifications, will be submitted by him to the committee on March 1, 1915. Applications must be received by the Secretary of Columbia University before this date.

The committee requires that applicants should be qualified by proper geological training and experience to undertake the investigation of some problem in or related to economic geology. Each candidate is expected to submit with his application a definite statement of the problem which he proposes to study. The carrying out of the investigation will be made under the oversight of the committee and may be undertaken at any place or institution which may be preferred by the holder of the fellowship and which will meet the approval of the committee. The place and

[1] Geologists, mining engineers and others interested in applied geology are invited to keep the editor informed of new investigations of mining districts or scientific studies undertaken by them, together with such other scientific and personal items as may come to their notice.

publication of results will be decided by the committee. The committee will require that the holder of the fellowship agree to give his entire time and energies to the problem selected, and further agree to contract no other engagements conflicting with or restricting this work without its consent. No objection will be made to the use of the results as a dissertation for the degree of Ph.D. in an approved university.

THE gold medal of the Hayden Memorial Geological Award was presented to Dr. Henry Fairfield Osborn in recognition of his paleontological studies at a special meeting of the Academy of Natural Sciences of Philadelphia on November 24. The presentation address was made by Dr. Samuel G. Dixon, president of the academy.

MESSRS. Laney, Spencer, McDonald and Hunter, of the U. S. Geological Survey, have recently been in Santa Rita, N. M., and vicinity, covering the geology of the country included in the Santa Rita special map of the Survey three years ago.

GEORGE E. ROBERTS has resigned his position as director of the United States Mint. He has accepted the position of assistant to the president of the National City Bank of New York, an office recently created. He expects to take up his new duties in a few weeks.

WALTER HARVEY WEED, who purchased the Horace J. Stevens "Copper Handbook" business following the death of Mr. Stevens and has since continued the business at Houghton, Mich., has moved the publication offices to New York City.

PROF. ROBERT H. RICHARDS was tendered a complimentary dinner in Boston on November 27 in recognition of fifty years' service as a devoted alumnus and teacher of the Massachusetts Institute of Technology.